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SOIL CONSERVATION IN KENYA COLONY

PART I. FACTORS AFFECTING EROSION, SOIL CHARACTERISTICS AND METHODS OF CONSERVATION

COLIN MAHER

(*Senior Soil Conservation Officer, Dept. of Agriculture, Kenya Colony*)

Introduction.—ONLY those who have lived in the tropics can appreciate the severity of tropical rainfall and the disastrous effect which the heavy rain may have upon the exposed soil. The soil conservationist in Kenya Colony has to make his plans in expectation of as much rain in an hour as may fall during a wet month in most parts of England.

The grave erosion which occurs on ploughland from time to time has often induced an 'old-timer' to say ruefully that we should never have put a plough into Africa. However, the relatively unscarred Africa which carried a small population on the basis of shifting cultivation remained curiously unprogressive in a world which was advancing in scientific knowledge by leaps and bounds. Western 'interference' caused the population to increase while accelerating the rate of deterioration of the soil; but this interference also gave the means of feeding the growing population; and adaptation of American techniques in soil conservation, grafted on to something of English husbandry and to what is known of ways of 'gardening' tropical soils, promises to solve the technical problems of preserving soil fertility—though there is indeed much still to learn. The phrase 'technical problems' was used advisedly. As Kellogg says [1], 'the biggest problem is not the soil directly but the people on the soil. Soil must be used by good farmers to remain productive. The emphasis must always be on the people who care for the land, not directly on the land. A poverty-ridden people pass their suffering to the soil'. In this article some description will be given of the soil problems of Kenya with which the European settlers have to strive, or with which they have to be induced to strive, and the methods and stratagems which are employed to secure or improve the soil fertility. The technical difficulties are similar and often identical in the native areas; but superimposed are a formidable number of biological, sociological, and economic tangles some of which were mentioned briefly by Liversage in this *Journal* [2].

Rainfall.—Most parts of Kenya have at least one pronounced dry season when grasses and bushes tend to dry up and during which stock, if not assisted with supplementary fodder, are apt to have a lean time comparable to that suffered by the stock in England in medieval times before the growing of foodstuffs for winter feeding became general practice. The monsoon rains generally begin in March or April and again in October, but areas such as the Uasin Gishu and Trans Nzoia districts (only about 50–100 miles from Lake Victoria) tend to have one long-drawn-out wet season with the heaviest rains falling in July and August when the 'down-country' districts are generally suffering from a

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more or less marked drought. Some districts are reputed never to receive more than 1½–2 in. of rain in 24 hours. Most districts at all altitudes in Kenya are liable, however, to receive rains of such intensities as 2 or 3 in. in an hour; 4½ in. in an hour; 7 in.—or even 10 or 11—in a night; 17 in. in 3 days; and so forth. Recording gauges of Friez pattern have been installed at several stations in the Colony for 10 years. It is proposed now to obtain additional Dine's rain-gauges (made by James J. Hicks of Hatton Garden) of a special type suitable for high-intensity rains falling during periods of a few minutes.

The damage done by the rain varies according to those factors with which soil conservation workers are so familiar [3, 4]. Successful soil conservation rests in modifying the effect of those factors which are not controllable by man by means of changing or tempering those other factors that are susceptible to alteration. Before more is said it must be admitted that the methods used by the Soil Conservation Service in Kenya are based chiefly on American experiments, on trial and error, and on practical experience in this type of work for over 15 years. There should be scope, it is true, for correlating with erodibility of tropical soils measurements of physical fractions of the soil, permeability of the soil, clay types, Hardy's 'sticky point' figures, measurements of soil structure, and other indices. The field is wide open for such work; but up to the present there has been a lamentable dearth of soil scientists to carry it on. Crop yields were falling, soil was running into the rivers and blocking up the roads, and something had to be done.

Soils.—The soils which have been dealt with consist of all kinds of 'red earths', as Vageler described them, and 'yellow earths' of various degrees of laterization; of grey ash soils; grey and black clays of various descriptions; or, to vary the nomenclature, sandy loams, loams, silts, and variations of these soils. Soils of different ages, residual and sedimentary, old lake-beds of the Post Tertiary period, old loessial deposits; soils derived from granites, gneisses, and schists of the Basement Complex, such as the sandy soils of the Trans Nzoia, parts of the Uasin Gishu district—and the Ukamba districts notorious for land abuse and erosion; chocolate volcanic loams from lavas and tuffs of the Tertiary and Post-tertiary periods on the slopes of Mount Elgon, from rocks of the Pleistocene to Miocene series of the Tertiary group on Mount Kenya and the Aberdares; grey volcanic-ash soils around Menengai near Nakuru, the farming centre of the Rift Valley, thin acid red soils over sheets of partially laterized phonolite lava on the Uasin Gishu plateau. Erosion has been showing itself on all these soils in varying degree for the past 20 or 30 years according to the way in which the land has been used and the period for which it has been cultivated.

Although there has been little or no laboratory examination of the physical properties of these soils in relation to their liability to erode, it was observed years ago that the characteristics mentioned by Bennett [4] in the U.S.A. held good on Kenya soils. Highly-weathered soils, such as the deep red earths of the Kakamega district with a low silica-sesquioxide ratio, are remarkably resistant to erosion. The subsoils of such soils and of volcanic loams on Elgon can indeed carry water in irrigation

furrows at comparatively high velocities for years without scouring noticeably any deeper. Again, in East Africa also, 'coarse grained soils usually are less resistant (probably up to the texture of coarse sand) to concentrated flows of high velocity than fine-textured soils', and similarly 'almost without exception soils of low organic-matter content are subject to comparatively rapid erosion' [4].

Apart from the question of rainfall intensity, the importance of which is self-evident, the amount of erosion that occurs is materially affected by the degree of saturation of the soil at the time of the rainstorm. The worst erosion usually occurs either when rain falls on a dry or almost dry soil or when the soil is already saturated. In the first case, particularly when the structure of the soil is powdery or approximating to a 'single grain' structure, there is a tendency for the top inch or two of the soil to become saturated and to cap or seal over, when the top of the soil may be washed down the slope although the soil underneath is bone dry. W. D. Ellison, of Coshocton Hydrologic Investigational Station, Ohio [5], has discussed in many articles the phenomena of 'splash erosion' or 'rain drop' erosion and surface flow of soil. 'Splash erosion' undoubtedly is a potent factor in the movement of the finer particles of the soil out of the top inch, into the surface drainage water and into the rivers or over the vleis. Such a reassortment of particles takes place in East Africa not only on arable land but on the exposed ground left between tufts of burnt grass in the bush at the end of the dry season. When the ground is already soaked it is evident that water flowing, perforce, on the surface of the land is certain to carry soil particles with it; and it should be remembered that fine clay particles can be carried by water flowing at a velocity of only 0·25 ft. per second [6]. This occurrence happens the more readily on soils with an impermeable clay subsoil, since on such soils water does not penetrate to any extent below the depth of cultivation, and in a rainy period water appears on the surface.

Soil Structure, Organic-matter Control, and other Factors influencing Erosion

The power of the soil to absorb rainfall is powerfully influenced by its structure and by the extent to which the soil is held in aggregates. For example, a few years ago a striking example was seen after a heavy rain on two adjoining fields on Mount Elgon. One field had just been broken from virgin grass and bush for its first maize crop; no water was standing on this field and no soil movement was apparent. Next to it was a field which had been cultivated for 15 years or so; here the water flowing down the slope had streaked the field with wash-lines and carried fans of silt into the terrace channels, and in between the deltas of eroded soil were standing pools of water that could not be absorbed by the soil of the field.

Amongst the factors capable of modification or suggestive of a change in method of land-use are the length and severity of the slope. On terraced land the only length of slope of much practical interest is the length permissible between the terraces; but here a compromise has to be made between making the terraces near enough together to reduce the

inter-terrace erosion to negligible proportions and placing them far enough apart to avoid making ploughing and cultivating excessively difficult.

Lastly there are the important matters of the system of farming and the methods of tillage. All-important is the question of protecting the soil from the beating rain-drops. The leaves carpet the soil against the flowing run-off water; the myriad rootlets bind the soil against the urgent clutch of the rivulets and in dying provide innumerable pore-spaces into which the rain can percolate. The primitive cultivator probably was able to move on to more weed-free and remunerative land before erosion occurred on the exhausted field which he had cropped for two or three seasons. In the meantime his mixed crops and his close-growing millets and sorghums gave an adequate cover to the soil except for a short period immediately after planting.

In contradistinction, the European maize or wheat farmer not infrequently has cropped his land for 20 or 30 years without respite. Row crops like maize are notoriously bad for permitting erosion. Cleanliness of the ground has to be maintained for 3 or 4 months after planting. Wheat, indeed, gives a good protective cover after the first 3 or 4 weeks; but the small grain cereals and flax or linseed need a fine tilth in the seed-bed which may be admirable under European conditions but which means disquiet for the Kenya farmer until the young plants have met over the soil. In some of the wheat areas this risky tilth has to be obtained immediately prior to the heaviest rains of the year, and losses estimated at 100–300 tons of top soil per acre have been observed on small areas following very heavy rainstorms falling during a 2- or 3-day period immediately before or after seeding.

Tillage and its effect on erosion.—Excessive use of implements like disk-harrows and tooth-harrows (especially) tends to leave the soil in a state in which it is particularly likely to suffer serious soil movement. Indeed the use of tooth-harrows to remove seedling weeds in a young maize crop is a very questionable procedure in Kenya as even the tine marks in the pulverized soil are sufficient to concentrate the flow of water with its burden of silt and clay (or even of sand) and to cause disastrous loss of fertile soil from the field.

Similarly the use of ploughs and harrows in the dry weather appears to have an unfortunate result upon soil structure. The unfavourable effect of the use of implements during the hot dry season is probably reinforced by the increased biological activity in the soil, or at times the more rapid chemical oxidation, causing accelerated loss of the cementing humic material. On the other hand moist soil ploughed up at the beginning of the rains has a more kindly appearance with a more evident crumb-structure. Too often, unfortunately, a farmer does not have sufficient equipment to prepare his arable land for planting at the beginning of the main rains. He is apt, therefore, to plough much of his land ahead of the main rains when the soil conditions are not of the best for good tillage. Do what one will, however, the violent storms later in the season tend to beat down the surface soil to a smooth surface. A local and temporary water-logging seems to be caused in sandy soils and,

on the poorer soils, a yellowing of the crop is probably associated with poor aeration and poor opportunities for nitrifying bacteria. Where too assiduous cultivation has been applied to the soil this 'panning down' of the surface will appear earlier in the life of the crop, however. Such cultivation is too often carried out by a farmer whose husbandry is founded on routine and custom rather than on thought and understanding of the needs of the soil and crop. Erosion usually occurs on soils whose fertility has declined and soil structure has deteriorated following years of cropping.

It is curious that on soils of volcanic origin in the Ol Joro Orok wheat-growing areas severe erosion may occur nevertheless without any marked falling off of soil fertility. Wheat may show vigorous growth in immediate proximity to washes or minor gullies from which the soil has been removed down to the plough sole. This observation was borne out by analyses of soil from such an area made by Mr. Gethin Jones, Senior Soil Chemist, Kenya Colony [7].

The field from which the samples were taken had been cropped with wheat, flax, and pyrethrum from 1942 to 1948. Yields of wheat were stated to have been up to 10 bags (of 200 lb.) per acre. This field with an average slope of 7 per cent. suffered severe sheet erosion during the early rains of 1948, and silt from the field flooded over an adjacent public road. The lower part of the area was badly gullied by the end of 1948. Soil samples were forwarded to Gethin Jones, who has not yet completed an examination of the soils but gives the following details regarding the samples from the top 12 in.:

	Virgin soil	*Cultivated: not eroded*	*Cultivated: eroded*
pH	(1) 5·7 (2) 5·6	(3) 5·4 (4) 5·3	(5) 5·6 (6) 5·3
N, per cent.	(1) 0·22	(3) 0·18	(5) 0·16

Gethin Jones commented: 'The values of 0·18 and 0·16 for total N show that these soils, apart from their erodibility, still have a good chemical fertility. There has not been much falling off as compared with the adjoining virgin soil.'

Some Characteristics of Eroding and Erodible Soils

Although soils suffering erosion have not necessarily lost too much fertility to be able to support a reasonably good crop, they have almost invariably lost their crumb-structure. Volcanic soils on Mount Elgon and in the Kikuyu Reserves develop a powdery surface, partly due to too much cultivation and trampling by labourers or stock, but also due, it seems probable, to the effect of desiccation and heat during the dry season. Several inches of this dusty surface soil may be removed and swept down a slope during a heavy storm to lie in the valleys or pans, to be carried in an almost viscous chocolate flood in the streams, or to be deposited to choke up terrace channels, so causing over-topping of the terrace banks by the run-off water. If such catastrophic events do not

supervene at least the soils will tend to pan down and give unhealthy, poorly aerated conditions to the growing crops.

Crops growing on the sandy loams or red earths derived from gneisses and schists depend chiefly for their nutrients on the top few inches. Here has accumulated most of the organic matter, nitrogen, calcium, and phosphates of the soil, thanks to the activities of the soil-searching roots of the trees, bushes, herbs, and grasses of the tall-grass savannah. The organic-matter content of such soils may start at about 6½ per cent. initially, being reduced under cultivation to little more than 2 per cent. In the hotter, more arid districts such as Ukamba, the organic matter content may be under 1 per cent. in the top soil. The pH values of a typical red earth in the latter area (40–75 per cent. sand) varied, increasing with depth, from 6·7 in the top 2 in. to 7·2 at 7 ft. and 8·2 at 12 ft. A yellow earth (55–80 per cent. sand) from the same district (Kitui) gave normal pH values of 6·4 at the surface, 8·3 at 7 ft., and 9·0 at 12 ft. The top few feet of corresponding soils in the 40–60 in. rainfall areas, however, have been thoroughly leached of calcium and show increasing acidity with depth. A typical virgin profile in the Trans Nzoia had a pH of 5·9 in the top 3 in. and a pH decreasing with depth down to 5·5 at 7 ft. and 4·8 at 13 ft. A profile on similar soil on land cultivated for some years in the same district showed pH values of 5·8 at the surface and 5·2 at 6 ft. 9 in. [8].

The phosphates in the soils in the moister districts are chiefly in the form of insoluble and unavailable aluminium and iron phosphates. The loss of the top few inches, therefore, has extremely serious effects on crops, and maize yields on eroded lands may be reduced from an original 15 bags an acre soon after breaking the virgin land to 3 or 4 bags an acre —an uneconomic return—8 or 10 years later.

There is no such great difference between the top soil and subsoil of the loess soils of the much-publicized Dust Bowl of the U.S.A. More serious in long-term effect, though less spectacular and of less value to the publicist, has been the loss of top soil from the red soils of the Southern (cotton) States; similarly the loss of top soil from the red earths of the Trans Nzoia, Uasin Gishu, and Ukamba Reserves presents an economic and technical problem for rehabilitating the soil which is far more difficult than is presented by the younger grey ash soils, rich in mineral nutrients and not yet highly weathered, that are found in the Nakuru, Solai, and Rongai areas of the Rift Valley.

The deteriorated red earths upon which cereal yields have dropped to submarginal economic levels have a characteristic appearance. They powder down almost at a touch to a single-grain structure that caps over and then is liable to be washed into minor gullies, which may develop into major gullies many feet deep so that implements are unable to cross. These gashes are likely to cause the drying-out of the surrounding land for many yards on either side. Deteriorated overcropped land on the other hand frequently ploughs up into hard greyish clods which do not break up under normal cultivation and do not fracture in the field through the normal wetting and drying processes. The rains beat on these clods with no more apparent effect than of merely rounding the edges. If

trees can be established on land of this kind, such as Eucalyptus spp., they will generally do well, as they appear to be able to make use of the unweathered minerals lower down in the soil profile that are not readily accessible to the less deeply rooted annual crop plants. If left to revert to natural pasturage the grasses which appear for the first 8 or 10 years on old tall-grass savannah land in the 40–60 in. rainfall areas are chiefly the pioneer grasses of poor nutritive value such as *Rhychelytrum repens*, Blue Couch (*Digitaria scalarum*), False Star Grass (*Chloris pycnothrix*), *Harpachne schimperi* and various Eragrostis spp. such as *E. chalcantha*, *E. tenuifolia* and *E. Chapelieri*. Even after 10 years of such natural reversion, the cover to the ground is frequently incomplete and the grazing of mediocre value, though more valuable grasses may start to appear, such as the Cynodon spp., *Brachiaria brizantha*, *B. soluta*, Rhodes Grass (*Chloris gayana*), *Trichopteryx kagerensis*, as well as the coarser, taller veldt grasses such as Hyparrhenia spp., *Setaria aurea*, Red Oat Grass (*Themeda triandra*) and various legumes of little grazing value, some of them bushy in type.

If this land is ploughed up again without due care or necessary precautions, the land may start to erode again and the old 'washes' to deepen and scour once more.

The degree to which such land can be restored by fertilizers, and by the use of planted grass leys, perhaps with no more than 2 years of cultivation in between leys, is a question which is largely conjectural until more experiments have been carried out; and the economic question of how much capital can be put into such reclamation schemes and yield a profitable return is a matter of particular moment.

In general the subsoils of the Kenya soils are, fortunately, resistant to erosion. Thus there is a general tendency for gullies or washes to widen rather than to deepen into the canyon type—though even so there are not lacking gullies of the type to which the time-worn remark is applied that a coach and horses could be driven down them. Exceptions to this generality are some of the ash soils between Elburgon and Eldama Ravine, and the ash deposits near Njoro and Rongai in which the exposure by erosion of pumice cinders leads to rapid deepening of gullies. Other soils lacking sufficient resistance are of course the deflocculated soda soils in the vicinity of existing lake-beds or of former lake-beds, such as are common in the Kamasia Reserve in the region of Lake Hannington or near the old Kamasia Lake-beds. Yet another soil upon which gully erosion rapidly ensues if the top soil is removed down to the more erodible subsoil is in the vicinity of Nanyuki on the lower slopes of Mount Kenya, where the soil is derived from lavas of the Mount Kenya volcanic series (Miocene to Pleistocene).

Soil-conservation Methods and Techniques in Kenya Colony

From the inception of soil conservation work in Kenya Colony—and broad-base terracing was used by some farmers as long ago as 1932 and contour ditching several years before that—the methods employed have closely followed those advocated and practised in the U.S.A. The Soil Conservation Service (S.C.S.) in Kenya Colony was formed as a separate

section of the Department of Agriculture at the beginning of 1938, and worked throughout the war years, though greatly handicapped by lack of staff and machinery till after the war. From the beginning the senior officers of the Service were impressed by the necessity for considering soil conservation as inseparable from good husbandry and depending for its effectiveness on being planned as a whole, taking advantage of all agronomic and engineering techniques available. The keynote of efficient soil-conservation work must be to obtain correct land-use, having in mind the climate, soils, topography, and markets. During the past 20 years there has been a flood of articles, booklets, pamphlets, handbooks, and books from the U.S.A. relating to land-use planning, especially from the Soil Conservation Service directed by that world figure in soil conservation, Dr. Hugh Hammond Bennett. Typical publications describing land-use planning technique are the *Soil Conservation Survey Handbook* published in 1940 by the Physical Surveys Division of the Soil Conservation Service, and, on the educational side, *Conserving Farm Lands* published by the U.S. Department of the Interior in 1939.

The small Soil Conservation Service of the Department of Agriculture in Kenya has never been able to provide the comprehensive teams of surveyors, agronomists, soil specialists, engineers, and soil conservationists, who customarily prepare farm plans and assist in their execution in the U.S.A. Indeed, it was some years before farmers and even some of the junior officers of the S.C.S. itself were convinced themselves of the desirability and practicability of complete planning of farms for soil conservation. The first requirement is a contour map and generally only cadastral sheets were available. Officers, assisted by educated African staff, who learnt to take over more and more of the work, had to prepare their own contour maps in detail, ranging from maps with contours every 50 ft. to plans with contours at 5-ft. or even 1-ft. intervals. Most of the work of this nature was done by plane table surveys. Sometimes, in haste, even this had to be dispensed with and farms planned 'on the ground'. It is hoped that some help will be obtained in the future from the maps to be prepared from aerial surveys by the Colonial Survey Unit; but it is likely to be a year or two before such maps will be freely available and even then the scale is small and additional detail will have to be added on the ground.

Fields, roads, and fence lines are re-aligned in a typical farm plan. Steep slopes are restored to trees or grass, generally by agreement, but if necessary by order of the Director of Agriculture (advised by his field officers). Drainage lines are put down to protective grass. Rotational systems are worked out by district agricultural officers, having in mind the economic needs of the farm, though here the work is frequently hampered by the inadequacy of information on crops, grass species, and fertilizers owing to insufficient experimental work having been possible during the past quarter century. Diversion ditches and terraces of various descriptions are included in the scheme and constructed under the supervision of the S.C.S., usually with tractors and machinery operated by it. A more detailed discussion of the farming and conservation methods advocated will follow below.

The Preservation or Improvement of Soil Structure

Grass leys.—In East Africa, Martin [9] drew attention to the effect of grasses, some of which seemed to be more efficient than others, in binding soil particles into the desired aggregate or crumbs. This indeed was no more than giving scientific approval to the shifting-cultivation method of restoring fertility formerly employed by the indigenous cultivator; though, especially for reasons of ease of clearing with hand-tools and fire, forest and bush land was generally preferred by Africans to grassland. It has been mentioned earlier that relatively little benefit seems to be given to the soil by the pioneer grasses of 'reverted' pasturage. G. ap Griffith, Senior Chemist of the Department of Agriculture, Uganda, found in an empirical and preliminary experiment that better results were given indeed by pigeon pea (*Cajanus cajan*) in causing crumb-formation than even by the more promising ley grasses such as Rhodes grass.

At present soil scientists are not agreed on the best method of measuring crumb proportions since 'organic' crumbs tend to break down under wet sieving. The mechanism of the crumb-forming process induced by products formed by micro-organisms is being investigated notably by Geoghegan of Imperial Chemical Industries at Jealott's Hill, who has described the ability of various polysaccharide substances to act as cementing agents for crumb-formation [10].

There is always a tendency for farmers—and even agricultural scientists!—to seize upon some panacea for farming ills. The use of grass leys, with the repeated blessings of Sir George Stapledon and with a resuscitation of the Clifton Park system of farming in agricultural circles in England, has come to be thought the golden key to erosion difficulties. Three years' grass and three years' arable, and good-bye to all craven fears of the result of 'putting a plough into Africa'.

After a protracted gestation period of over 15 years a ley system based on Molasses Grass (*Melinis minutiflora*) and Rhodes Grass has been claimed as being alive and kicking and indeed past its teething troubles in certain districts of Kenya. Other districts at high altitudes are less fortunate. Trials of cocksfoot, rye-grass, and other British stand-bys so far have been disappointing. *Phalaris tuberosa*, from the Mediterranean via Australia, has its adherents, and *Bromus marginatus*, a prolific seeder, has been used on some scale though it has shown a pampered predilection for the richer soils which narrows its use as a soil restorer. So far so good. Grass leys have come to stay, there is no doubt. Water indeed runs clear off a field well covered with grass, ley grasses give more grazing and stock thrive on them. It is hoped that their efficacy may be improved not only by the natural growth, in some areas, of Kenya Wild White Clover (*Trifolium johnstonii*) but by addition of indigenous legume seeds to the grass mixtures. *Alysicarpus glumaceus* is giving hopeful indications in this direction.

Now from the soil-conservation point of view it is time to sound a note of warning. Grass roots, lignified as they may be, soon disappear under the combined influence of the insect life, the microflora and microfauna of tropical soils and the moist and hot, or alternatively the hot, dry

oxidizing conditions that occur in Kenya. Vageler suggested that nitric acid in the tropical rains also acts as an oxidizing agent [11]. It is obviously impossible to build up in 2 or 3 brief years a mass of roots and an organic-matter content comparable to that contained in the virgin sod turned over after thousands of years of protection: and that same age-old fertility disappears under cultivation in 8 or 10 years or less. From field observations made by the writer there is reason to believe that the effect of grass roots in binding soil into crumbs may have disappeared in the second year and certainly by the third, thus reducing the high absorptive capacity of the soil that is noticeable immediately after ploughing ley grassland, and allowing the panning down of the soil and sheet erosion to continue once more. This fear is given substance by the results of an experiment carried out at Zanesville, Ohio, in which three crops of maize were taken after ploughing in a heavy grass crop. Soil losses were only 31 tons per acre in the first year but increased to 106 the second year, and 132 in the third, showing that resistance to erosion lay in the grass roots. As these decayed soil losses increased.

Green manuring.—Green manuring has been carried out in the districts with sufficient rainfall (an average of 40 in. annually and upwards) for many years, the practice being given a fillip by the results of experiments reported by Maher in 1932 [12]. The usual practice on maizeland is to devote one year in three to growing two crops of a green manure crop, usually sunflowers. (A crop of sunflowers is often grown also during the early part of the season and ploughed in before planting wheat.) This routine has succeeded in keeping up maize yields quite successfully. One well-known grower in the Trans Nzoia considers it economic to grow maize and sunflowers in alternate years. However, land on which this practice has been maintained for about 18 years now does not show a desirable soil structure—difficult indeed to maintain on soils classified as 'sand' by Hardy's Index of Texture; and it is doubted that this practice can be continued much longer without soil deterioration occurring to a point at which terraces will be powerless to stop serious soil movement.

Farmyard manure.—The benefit of farmyard manure or 'boma manure', as it is known in East Africa, in assisting the formation of crumbs is being doubted in temperate countries. In East Africa it has been recognized that the decomposition of manure or its demolition by termites is so rapid that its effect on soil structure is probably negligible, except possibly for a brief period immediately after application to the soil. Here again there is a need for research. At the East African Agricultural Research Conference held in Nairobi in 1947 many speakers decried the benefit of manure not only in improving soil structure but as a fertilizer. Kerkham of the Uganda Department of Agriculture spoke of an application of 30 t. of boma manure per acre on a field at Serere showing no benefit in the second year. Dr. B. A. Keen suggested that the ash-content of manure frequently would be enough to account for any apparent improvement in crop resulting from its application.

However, the better growth which the maize crop evidently makes after applying even small dressings of 4–8 t. of boma manure per acre

gives the making and use of manure an important place in soil-conservation programmes in Kenya Colony both at experimental stations and on farms controlled by experienced and successful maize growers. A good crop means a better cover to the soil. A fertile soil also gives a complete ground-cover of weeds in the latter half of the life of the maize crop when cleaning is neither required nor desirable.

Boma manure is generally made by bedding down the cattle yards or 'bomas' with wheat or maize straw—more commonly the latter, as wheat straw left on the land by the combines is too commonly burnt, a practice likely to accelerate soil deterioration and erosion. The Inspector (under the Land and Water Preservation Ordinance) in the Uasin Gishu, reporting 'appalling erosion' during May 1949 in the Sergoit (Uasin Gishu plateau) area caused by 11 in. of rain that fell in 7 days, mentioned three adjoining wheat farms: on the first straw had been ploughed in for several years and practically no erosion was to be seen (none at all on terraced land) and in 1948 the wheat yield was 6 bags of 200 lb. per acre. On the next farm the straw is burnt every year; a fair amount of erosion had occurred and the yield had been 5 bags per acre in 1948. Diversion terraces had been placed at intervals of 200 yds. apart on this farm. On the third farm there were no conservation measures at all and the straw is burnt every year. Erosion was 'appalling', and the wheat yield in 1948 had been 4 bags per acre only.

Ploughing under of crop residues.—The ploughing-in of maize or wheat straw does a great deal to prevent erosion by holding the soil open so that the absorption of the rainfall is facilitated. The presence of some of the material on the surface as a partial mulch is equally beneficial but may complicate planting and cultivation later. Opinions vary as to the benefits or otherwise derived by the crop from this practice. Particularly if the soil is not fertile (and presumably is rather deficient, relatively, in soil organisms) and dry weather occurs after ploughing in the crop, adverse results may accrue due to denitrification of the soil by the organisms feeding on the straw, which has a high C/N ratio. Striking results of this have been observed after ploughing in a double amount of maize stover. On the other hand good results may be obtained from the ploughing in of straw if this is partially covered by disking immediately after harvest, if early rains assist the decomposition of the material, and if well-rotted compost or a nitrogenous fertilizer is given to the succeeding crop.

Some farmers in the Njoro area on a volcanic-ash soil reasonably well provided with lime and phosphates claim good results from an early cultivation after harvest with harrow ploughs or 'one-way disks' which starts the process of rotting the straw in train. Probably the continuance of this practice over a number of years would give a good effect on the crops, following a build-up of the number of cellulose- and lignin-destroying organisms; but here yet again surmise and opinion take the place of controlled experiments.

In 1936 on a large farm at Njoro (on volcanic-ash soil) an increase in yield of wheat of 47 per cent. was obtained on land on which the wheat and barley straw had been ploughed in compared with the yield on land

from which the residues had been removed. In the same year at Rongai the crop from plots on which the stubble had been ploughed in averaged 11·21 bags per acre compared with only 9·2 bags per acre from plots from which the stubble had been removed [13].

Experiments carried out in Tanganyika in the dry Ardai area lent by the Masai to the Northern Province Wheat Scheme showed similar results in 1945. A statistically significant increase of 1·4 bags per acre was obtained on plots on which stubble had been ploughed under, above the average yield of 5·08 bags per acre obtained on plots on which the stubble had been burnt [14].

Maize stover can be moved fairly rapidly and economically from the field to cattle bomas by loading on sweeps dragged by oxen. It will not usually be sufficiently decomposed before the season after the next one or at any rate before a year has elapsed. It can be applied conveniently to a green-manure crop in the following September or ploughed in with a grass ley broken some time between June and October; alternatively, and preferably in the view of the writer, it can be applied by spreader and disked in a few weeks before the crop is planted in March–April. It is probable that losses through termites and soil organisms are high if the manure is spread 6 or 7 months before the maize crop is planted. Indeed dung dropped in grass paddocks is generally covered by the earth-casts of termites within a day of falling on the grass, and it is questionable how much of the value of such dung gets into the soil.

Cover crops.—Long-term cover crops are not generally either convenient or economically practicable, except in order to restore 'worn-out' land on farms on which the main emphasis is on cereal crops, with or without stock. However, the Madagascar butter bean (*Phaseolus lunatus*) grown for seed has some such effect. A cover crop of a crop like the Black Mauritius bean (*Stizolobium* or *Mucuna nivea* var. *aterrimum*) will produce, by leaf-fall and protection of the soil from the sun, a remarkable puffed-up appearance in the soil, intermingled as it is with black decaying organic matter. The indigenous legume *Glycine javanica* produces a similar effect, imitating the growth of forest mould. A leguminous bush sometimes used in Kenya and Tanganyika in tea and coffee plantations, and for regenerating land, is *Tephrosia vogelii*, a similar bush to *T. candida* but stronger growing under East African conditions. This plant is perennial and can be slashed down and mulched from time to time. Probably more use should be made in East Africa of such cover crops and bush green-manure plants.

The foregoing has touched upon methods of improving crumb-structure by adding to the humus-content of the soil by means of grass leys, green manuring, the use of boma manure or compost, and by long-term cover crops and bush green-manure crops. There remains to be considered the question of tillage operations.

Ploughing.—The unfavourable effects that are likely to be caused on tilth by ploughing in the dry season have already been mentioned and the desirability of avoiding excessive use of disk- and tooth-harrows. On heavy clay soils and even on the heavier volcanic loams ploughing in the dry season is not so likely to be deleterious, and on the heavier clays

deep ploughing in particular will be beneficial. On the lighter soil deep ploughing is likely to do more harm than good by exposing an excessive amount of soil to the tropical sun from time to time and causing too rapid decomposition of organic matter in the top few inches. Kellogg [1] remarks: 'In northern and eastern United States most farmers plow a slice about 6 to 8 in. thick. Usually plowing is shallower in the south. In the drier regions plowing is shallower, say about 5 to 7 in. in the Prairie soils of Iowa, 5 to 6 in. in the Chernozem soils of the eastern Dakotas, and 4 to 5 in. in the Chestnut soils further west. Rather than "plow deep while sluggards sleep" one should plow well, at the proper time, and as little as possible, yet kill weeds, develop good seed-beds, and make the soil receptive to rain water.'

REFERENCES

1. Ch. E. Kellogg, The Soils that Support us. The Macmillan Company, 1947.
2. V. Liversage, Colonial Land Tenure Research, Emp. J. Expt. Agric., 1948, **61,** 33–8.
3. Q. C. Ayres, Soil Erosion and Its Control. McGraw Hill Book Company, 1936.
4. H. H. Bennett, Soil Conservation. McGraw Hill Book Company, 1939.
5. W. D. Ellison, Studies of Raindrop Erosion, Agric. Engineering, April, 1944; Soil Erosion Studies, ibid., April–Oct. 1947.
6. Handbook of Erosion Control Engineering on the National Forests. U.S. Govt. Printing Office, Washington, 1936.
7. Private communication dated May 9, 1949.
8. Unpublished data from analyses by F. Hardy, Trinidad, of soil samples supplied by the writer in 1930 and 1937.
9. W. S. Martin, Soil Structure, East Afr. Agric. J., 1944; **9,** 189.
10. M. J. Geoghegan and R. C. Brian, Influence of Bacterial Polysaccharides on Aggregate Formation in Soils, Nature 1946, **158,** 837.
11. P. Vageler, An Introduction to Tropical Soils. MacMillan Co. Ltd., 1933.
12. Colin Maher, Maize Yields and Green Manuring. Govt. Printer, Nairobi, 1933.
13. Kenya Information Office, Fortnightly, October 30, 1944.
14. N. R. Fuggles-Couchman, Results of some Wheat Experiments in the Northern Province Tanganyika Territory, East Afr. Agric. J., 1946, **11,** 231.

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INFLAMMABILITY OF CEREAL CROPS IN RELATION TO WATER-CONTENT

D. J. WATSON

(*Rothamsted Experimental Station, Harpenden*)

EACH year, during dry summer periods, there are a number of outbreaks of fire in standing corn crops, but experience has shown that in this country they rarely reach serious dimensions. Although common sense suggests the broad climatic conditions in which the danger of fire is greatest, the subject has never been closely examined. The experiments described in this paper were undertaken during the war, in 1941, when it became important to define more precisely the conditions in which fires could occur. It was assumed that the most important factor determining inflammability of a cereal crop is its water-content, and it was therefore planned to investigate (1) the relation between inflammability and water-content, by means of laboratory and field tests, and (2) the variation of water-content of field crops of wheat, barley, and oats, especially of the straw, in relation to the stage of development of the crop and climatic conditions.

Unfortunately, weather conditions during the period before harvest in 1941 were very unfavourable for the work. In late July there was a series of heavy thunderstorms, and August was uniformly wet with only 7 days on which there was no measurable precipitation. The total rainfall in July and August at Rothamsted was 9·8 in., nearly twice the average of 5·1 in., and, in consequence, harvest was delayed by a fortnight to 3 weeks. The water-contents of the crops were probably very abnormal and the inflammable state was reached only in crops which were deliberately left standing for some time after the stage when they were fit for cutting. The work was not repeated in a subsequent season, but as so little information exists on the subject a short account of the results may be of interest.

Field tests of inflammability.—As dry straw will burn readily whilst wet straw cannot be ignited, it may reasonably be assumed that there is a critical water-content for inflammability. The object of the field and laboratory inflammability tests was to determine this critical value. The field tests were made on three dates at weekly intervals (August 20 and 27, and September 4) on crops of wheat and barley. Igniters consisting of sheets of thick celluloid with a rubber core were used to provide a standard flame. These were dropped on the ground in the crop and lit with a match. Samples of the crops were taken at the time of the tests, and the water-content of the basal 6 in. of the straw, and of the remainder, including leaves, was determined after cutting off the ears. The water-contents given below are expressed as per cent. of fresh weight.

None of the wheat crops (varieties Yeoman and Wilhelmina) tested was inflammable. Immediately after the igniters were lit, a few shoots

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close to them were burnt, but there was no further spread of fire, although the igniters continued to burn for several minutes. The lowest water-content of the shoots was 36 per cent. in the upper part on September 4; the critical water-content must therefore lie below this.

The barley crops were drier than the wheat, and in several of the tests there was a rapid spread of fire from the point of ignition. A crop of Tall Kenia barley was found to be inflammable on August 20, and about 16 sq. yds. of it were burnt before the fire died out. The upper part of the shoots of this crop contained 33 per cent. water, the basal part 54 per cent., and it was noted that the straw was not burnt closer to the ground than 3–4 in. The same crop was tested again on September 4 when the water-content of the upper part of the stems was 22 per cent., and on this occasion the fire did not spread so rapidly, suggesting that inflammability depends on other factors than water-content. Crops of the later-maturing Plumage Archer variety were not inflammable when tested on August 20 and 27, when the water-contents of the upper part of the shoots were 48 and 43 per cent. respectively. But on September 4 in one field where the upper part of the shoot had a water-content of 27 per cent., fire spread rapidly from the point of ignition and would, apparently, have continued indefinitely if not extinguished. In another field of the same variety, where the water-content of the upper part of the shoots was a little higher, 29 per cent., the crop appeared to be very close to the critical condition. The drier shoots burned readily but shoots with a water-content above the critical value were still present in sufficient proportion to prevent fire spreading. These observations indicate that the shoots of ripening cereal crops become inflammable when their water-content falls below about 30 per cent. of their fresh weight. The tests were not sufficiently numerous to locate the critical point precisely, if indeed it is sharply defined. It seems probable that the critical value varies within a range determined by other factors. For example, it is likely to depend on wind velocity and on the density of the crop.

Laboratory tests of inflammability.—A simple apparatus was devised to compare the burning behaviour of straws of varying water-content when exposed to a standard flame. The test measured the ability of an isolated stem to support self-maintained combustion, a condition in which burning is more difficult than if other stems are burning in close proximity and giving supporting radiation. A micro-Bunsen burner was used to provide a small horizontal flame, and was arranged so that it could be quickly turned to play on the base of a 15 cm. length of straw held vertically between two pins at a fixed distance from it. The length of the flame was adjusted so that the straw came into the hottest part, just clear of the cone. Three measurements were made on each straw:

(1) The ignition time; the interval between application of the flame and ignition of the straw, shown by the appearance of incandescence.

(2) The combustion time; the period after the time of ignition during which the straw continued to burn.

(3) The length of unburnt straw; the difference between this and 14 cm., the distance from the centre of the flame to the upper end of the straw, gave the length of straw burnt.

From (2) and (3) the rate of propagation of the flame could be calculated. Each test was made on 8–10 straws. The length of straw taken for each test was cut just below the second node from the base of the shoot, and included 15 cm. of the internode above, with the surrounding leaf-sheath. The flame was applied immediately above the node. In the barley shoots, the third node from the base came within the 15-cm. length, and often the flame was extinguished when it reached this node. Tests were made on three series of samples. One consisted of shoots taken directly from the field at two-daily intervals in the late stages of ripening. For another series a large sample of shoots was placed in a drying-room, and sub-sampled at successive stages of drying. In the third series, a large sample taken on August 21 was dried at 100° C., and sub-samples were rewetted to different water-contents by exposing them for varying periods to a saturated atmosphere or, for the higher water-contents, by soaking them in water. In the first two series, the water-contents at the time of testing were determined on duplicate samples. The results of tests on these series were very erratic, probably because of variation in water-content between individual straws and of differences in water-content between the straws used for the burning tests and for the water-content determinations; they will not be discussed here. The water-contents for the series rewetted after drying could be determined directly on the straws actually used for the tests by weighing them, since their dry weights were known. Also, the straws of a sub-sample were probably more uniform in water-content, for the results shown in Fig. 1 were more consistent than in the other series. It should be noted, however, that they may not be strictly applicable to field material, which may still contain living tissues. When these are killed by drying and subsequently rewetted the physical conditions in which water is held may be greatly altered.

The mean length of wheat straw burnt (Fig. 1A) increased rapidly with falling water-content between 40 and 30 per cent. Below 30 per cent. nearly all the 14-cm. length of straw was burnt. The results for barley were similar, but the length burnt was less than for wheat, particularly over the range of water-content from 40 to 20 per cent. The change in length burnt was largely determined by the proportion of shoots burnt completely (Table 1).

TABLE 1. *Variation with Water-content in the Number of Wheat and Barley Shoots burnt completely, and the Number of Barley Shoots burnt to the third Node.* (*Out of 8 for Wheat and 10 for Barley*)

Water-content, per cent.	40	35	30	27·5	25	20	10	0
Completely burnt: Wheat	0	1	6	..	7	7	8	8
Completely burnt: Barley	0	0	3	0	6	6	9	10
Burnt to node. Barley	2	2	2	8	2	0	1	0

Thus, for wheat, only 1 shoot was burnt completely at 35 per cent., at 30 per cent. the number increased to 6, and over the range from 25 to 0 per cent. only 2 out of 32 straws tested failed to burn completely. The difference between wheat and barley can be explained partly by the extinction of the flame at the third node, included in the 14-cm. length of barley straw used in the tests. At 27·5 per cent. water-content the flame died out at the node in 8 out of 10 straws, whilst at 25 per cent.

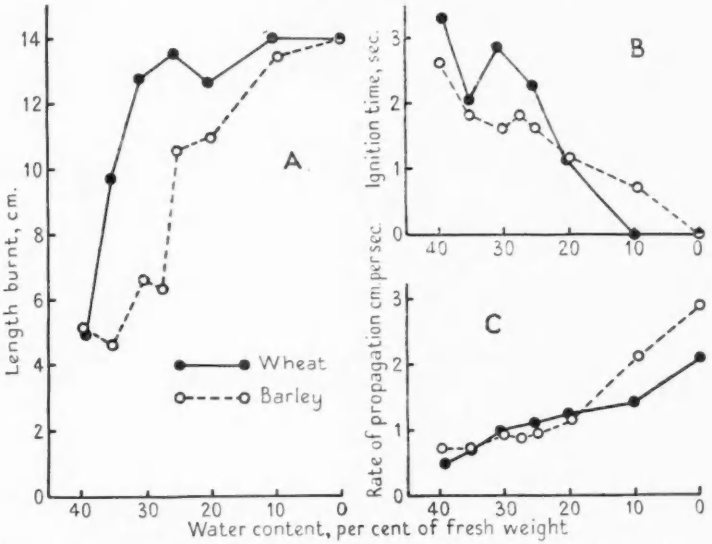

FIG. 1. The relation to water-content of (A) mean length of stem burnt, (B) mean ignition time, and (C) mean rate of propagation of flame in wheat and barley stems. Laboratory tests on straws rewetted after drying.

this happened in only 2 cases, 6 straws being completely burnt. If the barley straws had not contained a node, it may be assumed that the propagation of the flame would have continued, and that the majority of the shoots which burned only as far as the node would have burned completely, giving results very similar to those for wheat. A reasonable interpretation of these results is, therefore, that a flame will propagate itself indefinitely along a length of straw uninterrupted by nodes, when the water-content falls below 30 per cent., and that for barley a node acts as a barrier to the passage of flame when the water-content is higher than about 25 per cent. Unfortunately, the tests give no information on whether this is also true of wheat. It seems likely that a crop becomes inflammable when the majority of the shoots composing it are capable of burning completely if ignited. The field and laboratory tests are in agreement with this, for they indicate that the critical water-contents for inflammability of a standing crop and for unrestricted propagation of flame along individual straws both occur in the region of 30–25 per cent.

Ignition time (Fig. 1B) and the rate of propagation of flame (Fig. 1C) both varied almost linearly with water-content, the former decreasing and the latter increasing with falling water-content. There was no indication of a sudden change in the magnitude of either of them at any particular critical water-content. Evidently these attributes of burning-behaviour are not relevant to the determination of inflammability in the sense of unrestricted propagation of flame from the point of ignition. Nevertheless, in the region of water-content where unrestricted propagation occurs, changes in ignition time and rate of propagation probably affect the rate of spread of a fire through a standing crop, increasing it as the water-content falls.

Variation in Water-content of Cereal Crops during Ripening

The object of the second part of the investigation was to follow the change in water-content of cereal crops with time, and to determine the stage of ripening at which the water-content falls below the critical value for inflammability. It had been suggested that it might be possible to correlate water-content with the stage of ripening as judged by visual observation, so that the existence of a fire-risk might be detected merely by looking at a crop. Accordingly, notes were made of the appearance of the crops at the time when determinations of water-content were made. In practice, however, it is difficult to distinguish any sharply defined stages in the progress of ripening, for the yellowing of the leaves, stems, and ears, and the hardening of the grain are continuous processes without easily recognizable critical points. Also, these changes do not proceed at the same rate in all the shoots of a crop; some shoots may be completely yellowed, while others still have partially green leaves and stems.

Two sources of variation of water-content may be distinguished: (1) a steady fall associated with senescence and death of the tissues of the plant, and (2) short-term fluctuations induced by external factors. As the intensity of these factors varies widely from season to season, the date and the stage of ripening at which water-content falls below the critical value are also likely to vary. This must be borne in mind in considering the results given below, especially as the pre-harvest period in 1941 was abnormally wet.

Determinations of water-content were made on spring-sown oats (variety Star) and barley (variety Plumage Archer), and autumn-sown wheat (variety Yeoman) growing in normal agricultural conditions on Rothamsted Farm. An area of each crop was selected for uniformity, and observations were made at intervals of 2–3 days, continuing until after the crops were cut, the final determinations being made on the harvested sheaves and stubble. Harvest was delayed as long as possible so as to prolong the period of observation. On each occasion duplicate samples of each crop were cut close to the ground. A sample consisted of 2 metres of drill-row, divided between 6 adjacent rows. Spaces were left between neighbouring samples, to ensure that the removal of samples did not affect those taken on a later occasion. The samples were cut between 1 p.m. and 3 p.m. G.M.T., with a few exceptions when they

were taken earlier in the day in preference to omitting them altogether. In the afternoon the water-content is near its daily minimum, so the values recorded were dependent on the amplitude of the diurnal variation.

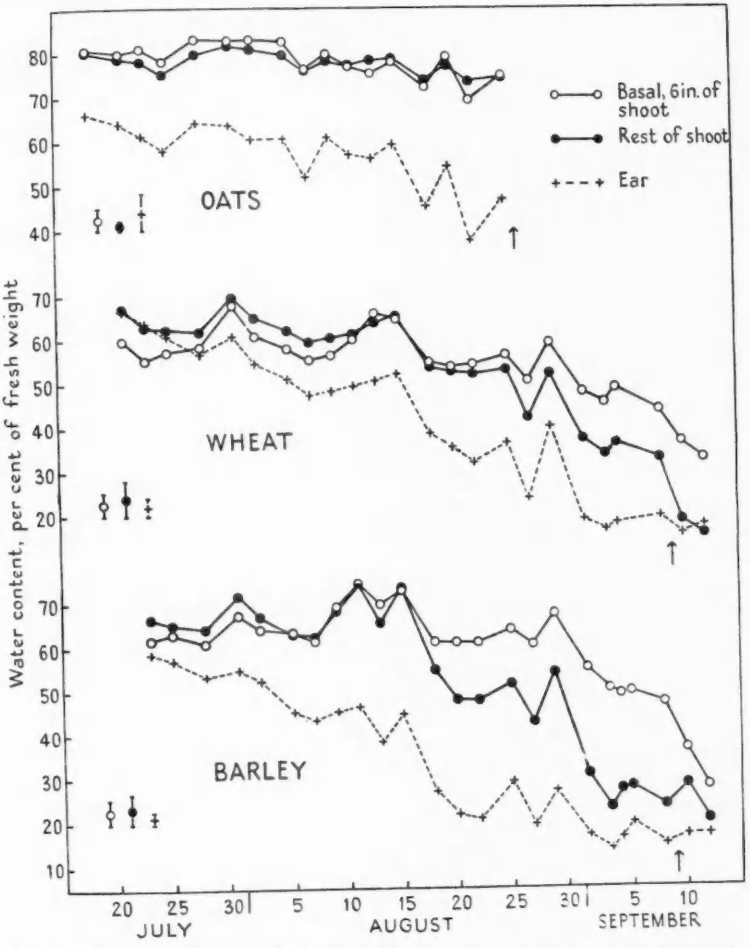

FIG. 2. Variation with time in the water-content, per cent. of fresh weight, of oats, wheat, and barley grown at Rothamsted in 1941. The vertical lines to the left of the figure show the magnitude of differences between sampling occasions that are significant at the 5 per cent. level. The arrows show the dates when the crops were cut. Observations after these dates were made on samples taken from sheaves (upper part of the shoot and ears) and from the stubble (basal part of the shoot).

Each sample was divided into three parts, (1) basal 6 in. length of

shoot, (2) remainder of shoot, including leaves, and (3) the ears[1] cut off at the basal notch. The parts were weighed separately, dried at 100° C., and weighed again. Water-content was expressed as weight of water per cent. of fresh weight. As it is impossible to remove all the water from intact cereal grains by drying at 100° C., the water-contents recorded for the ears are probably slightly too low. The means of duplicate observations on each occasion are plotted in Fig. 2.

Oats.—When the observations began on July 18, the oat crop was still green, and the first signs of yellowing were not seen until a week later. The water-content of the shoots increased from 80 per cent. initially to 83 per cent. at the end of July, subsequently falling slowly. It was still over 70 per cent. when the crop was cut on August 26. The basal part of the shoot had a slightly higher water-content until August 7, but later there was no consistent difference. The water-content of the panicle ('ear' in Fig. 2) was always much below that of the shoot; it decreased very slowly at first, from 65 per cent. at the beginning to 60 per cent. on August 15, and then more rapidly to about 45 per cent. at harvest. The crop was still very green when it was cut, though the grain was hard.

Wheat.—The lower leaves of the wheat plants were yellowed and dead at the beginning of the experiment, but the upper leaves, stems, and ears were still completely green. Throughout July and early August the basal part of the shoot had a lower water-content than the rest. During this time there was no obvious downward trend, but from the middle of August onwards water-content fell steadily. The fall was less rapid in the basal part, so that in September its water-content was about 10 per cent. greater than that of the rest of the shoot. The water-content of the ears decreased to about 18 per cent. at the end of August, and subsequently showed little change.

All other wheat crops on Rothamsted Farm had been cut by August 28. The sampled crop was dead ripe on this date and was fit to cut a few days earlier. The water-contents on August 27 were: basal 6 in. of shoot 50 per cent., rest of shoot 42 per cent., ear 24 per cent.; rain on the following day increased these to 59, 52, and 40 per cent. respectively on August 29. The crop was nearly 3 weeks late in ripening; wheat is usually harvested at Rothamsted in the first week of August.

After the crop was cut on September 8 the cut shoots dried out rapidly. On September 10 they had a water-content of 18 per cent., compared with 33 per cent. in the upper part of the shoots on September 8. The water-content of the stubble also continued to fall, but it was still above 30 per cent. on September 12.

Barley.—The drift of water-content in the shoots of barley was similar to that in wheat. The chief difference was that from the middle of August onwards the water-content of the basal part of the shoot was higher, and that of the rest of the shoot lower, so that during this period the difference between upper and lower parts was much greater than in wheat. Water-content decreased more rapidly in barley ears; by August 22 it had fallen to 22 per cent., compared with 32 per cent. for

[1] For convenience, the term 'ear' is used to include the panicle of oats.

wheat, and subsequently it changed very slowly—an expression of the earlier ripening of the barley crop. It was almost fit for cutting on August 13, about the normal harvest time, and by August 18 it was dead ripe, with all its leaves and stems yellowed and the grain very hard. The water-content of the shoots on August 18 was still over 60 per cent. in the basal part and 55 per cent. in the rest.

After the crop was cut the water-content of the stubble continued to fall, but there was little change in the cut shoots or ears.

The only definite conclusion that can be drawn from these results in relation to fire-risk is that, in a year of high summer rainfall, the water-content of the shoots of cereal crops at the stage when they are fit for cutting greatly exceeds the critical value for inflammability. In the present experiments the percentage water-contents of the upper, drier parts of the shoots at this stage were approximately: oats 70, wheat 45, and barley 55. Whether this is so in drier years is not known for, unfortunately, there are no data on the variation between different seasons in the water-content of the straw of ripe cereal crops grown at Rothamsted. It is probable that the water-content of oats is usually high at harvest, since the crop is commonly cut in a slightly immature condition, because the straw has a higher feeding-value than if left until fully ripe, and loss of grain by shedding is reduced. On the other hand, it seems certain that the water-contents of wheat and barley straw are often considerably lower than those recorded in the present experiments, especially if the crops are left standing for some time after they are ripe. In either case, whether the water-content at maturity is consistently of the order of 40–50 per cent., or whether it varies from season to season, sometimes falling below the critical 30 per cent. level, it is obvious that the stage of ripeness of the crop is not a useful index of the existence of a fire-risk. The results for barley, which showed a fall of water-content in the upper part of the shoot from 50 per cent. at the stage when the crop was mature in mid-August to about 25 per cent. when it was left standing for another fortnight, and the similar fall in wheat in the stage of post-maturity, suggest that the danger of loss by fire occurs mainly when harvest is delayed beyond the stage when the crop first becomes fit for cutting. Such delay frequently happens, for even if an attempt is made to spread harvest by sowing varieties that differ in their time of maturity, it may be impossible to cut all the crops as soon as they become ripe, if there is a large area to be harvested.

Relation of Water-content to Climatic Factors

The wide deviations of water-content from a smooth time-trend (Fig. 2) corresponded closely in wheat and barley, suggesting that they were caused by external factors producing similar effects in both crops. In oats, the deviations were smaller, and not very closely related to those in wheat and barley, though there was a tendency for maximum and minimum values to coincide in all three.

An attempt was made to account for the deviations by correlation with climatic factors. The most important factors that affect water-content are probably rainfall, acting indirectly by changing the soil-

moisture content and directly by wetting the plants, and temperature, atmospheric humidity, and air movement which control the rate of water-loss by transpiration. The change in soil-moisture content during a period when there is no drainage is determined by the amount of water added by rainfall and the amount lost by transpiration and evaporation. Assuming as a first approximation a constant rate of water-loss, a linear function of time and accumulated rainfall over the interval between the beginning of the experimental period and the time of observation will serve as a measure of soil-moisture content (Watson and Baptiste, 1938). Accumulated rainfall, however, is obviously not the determinant of the surface-wetting effect of rain, for this must depend on rainfall immediately before the time of sampling.

The most suitable temperature variate for correlation with water-content was thought to be the daily maximum temperature. The daily maximum occurs in the early afternoon at about the time when the water-content determinations were made, but it also serves as a measure of the temperature conditions in the earlier part of the day, because days when the maximum is high tend to be warmer throughout than when it is low.

The only available records of relative humidity were taken daily at 9 a.m., and are not likely to be an adequate measure of conditions later in the day. The mean wind velocity between 7 a.m. and 3 p.m. on each sampling day was obtained from anemobiagraph records. Partial regressions of water-content on these humidity- and wind-velocity variates were not significant and will not be discussed further.

The method adopted, therefore, was to fit a multiple regression of water-content in the different parts of each crop on time in days from the beginning of the period of observation, accumulated rainfall in inches over the same period, and daily maximum temperature. The coefficients of the regression equations are shown in Table 2. The standard errors of the regression coefficients were computed from the variance between duplicate samples within sampling times.

The regression coefficients on time show the magnitude of the daily fall in water-content, when rainfall and temperature are held constant. This change has a complex interpretation, being attributable to internal changes associated with senescence of the tissues and to loss of water from the soil in transpiration and evaporation; the two effects cannot be separated. All the coefficients were negative in accordance with expectation; those for oats were much smaller than for the other crops and were not significant.

For oats, the regression coefficients on rainfall were all smaller than their standard errors and hence did not differ significantly from zero. The only explanation that can be offered for this apparent absence of any effect of rainfall is that the oats were fully turgid, or nearly so, throughout the whole period of observation. When the rainfall term was omitted from the regression, the coefficients on time were increased and became significant, whilst those on temperature were scarcely affected.

The regression coefficients on rainfall were significant for all parts of

TABLE 2. *Regression Coefficients of Water-content (per cent. of fresh weight) on Time in Days, Accumulated Rainfall in Inches, and Daily Maximum Temperature (° F.)*

	Regression coefficient on:			*Per cent. reduction of variance*		
	Time	*Rainfall*	*Temperature*	*A*	*B*	*C*
Oats:						
Shoot—basal 6 in.	−0·1±0·35	−0·8±2·3	−0·13±0·08	42	38	−4
Shoot—rest	−0·1±0·14	−0·5±0·9	−0·22±0·03	31	51	20
Ear	−0·5±0·58	−0·1±3·9	−0·30±0·13	60	59	−1
Wheat:						
Shoot—basal 6 in.	−1·0±0·17	5·1±1·2	−0·35±0·07	40	57	17
Shoot—rest	−1·5±0·26	5·9±1·9	−0·49±0·10	76	86	10
Ear	−1·4±0·14	3·0±1·0	−0·29±0·06	89	90	1
Barley:						
Shoot—basal 6 in.	−1·5±0·18	8·8±1·3	−0·38±0·07	26	53	27
Shoot—rest	−2·3±0·22	9·9±1·5	−0·70±0·08	69	79	10
Ear	−0·8±0·08	−2·2±0·6	−0·03±0·03	91	90	−1

A = per cent. reduction of variance between sampling times attributable to regression on time alone.

B = per cent. reduction of variance between sampling times attributable to multiple regression on time, rainfall, and temperature.

C = additional per cent. reduction of variance attributable to rainfall and temperature terms.

the wheat and barley plants. They show that one additional inch of rain increased the water-content of wheat shoots by 5 per cent., and of barley shoots by 9 per cent., and in both crops the increase was smaller in the basal part than in the rest of the shoots. In the ears the effect was smaller still. The regression coefficient for barley ears was significantly negative; there is no obvious explanation for this apparent decrease of water-content with increased rainfall.

All the regression coefficients on temperature were negative, showing that water-content decreased with rise in the daily maximum. The effect of temperature on the water-content of the shoots, like that of rainfall, was smaller in oats than in the other crops. It was slightly smaller in wheat than in barley, and in the basal part than in the rest. The temperature coefficients for the ears of wheat and oats were nearly identical and of the same order as those for the shoots, but the coefficient for barley ears was very small and not significant.

Table 2 (column C) shows that the rainfall and temperature terms of the multiple regression together accounted for a considerable part (10–30 per cent.) of the variance between sampling times in the water-content of the shoots, except for the basal part of oats. For the latter and for the ears of all three crops, the inclusion of the rainfall and temperature terms in addition to the time term did not result in any further reduction of the variance; a regression on time alone fitted the data as well as the multiple regression on time, rainfall, and temperature (compare columns A and B, Table 2). This result at first sight

appears to contradict the fact that the rainfall coefficients for wheat and barley ears, and the temperature coefficients for oats and wheat, were significant. The explanation is either that other unknown factors had a greater influence on water-content than those tested, or that a more complex function than a linear regression is necessary to represent the full effects of rainfall and temperature.

A comparison of the observed values of water-content with values calculated from the regression equations is given in Fig. 3, for the upper parts of the shoots of wheat and barley. Notes made at the time of sampling suggest that many of the positive deviations observed from calculated values were attributable to the presence of surface moisture

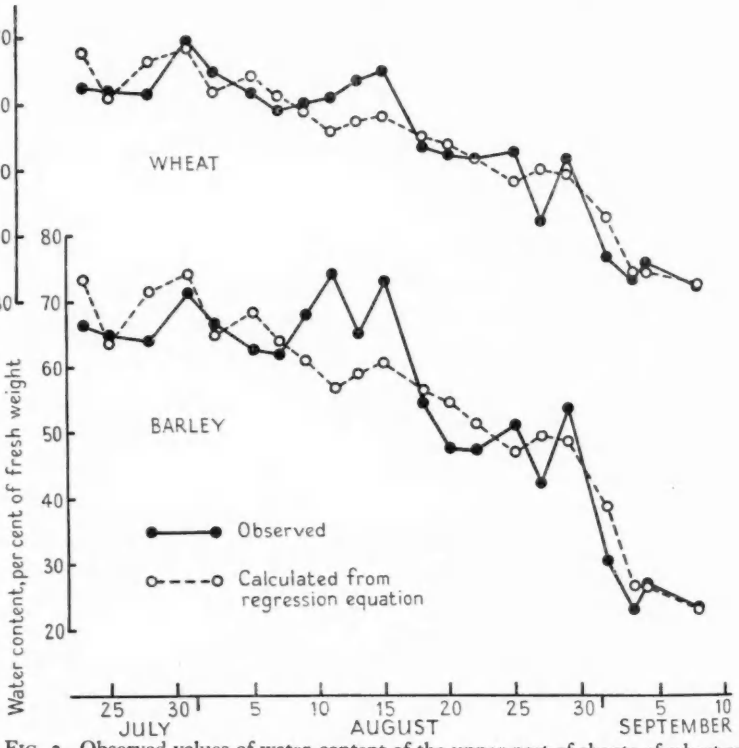

FIG. 3. Observed values of water-content of the upper part of shoots of wheat and barley, compared with values calculated from the regressions on time, accumulated rainfall, and daily maximum temperature.

on the plants. Samples were recorded as being damp or wet on July 31 and August 2, 9, 11, 13, 15, 25, and 29, including all the days when the deviations were positive except July 25 and September 4. On the other hand, samples were recorded as damp on August 5, 20, and 27 when the deviations were negative; for barley there was also a small negative

deviation on July 31. Although the presence of surface moisture is usually the result of recent rain, the amount of surface moisture and its effect in causing an apparent increase in the water-content of the plant may not be closely correlated with the amount of rainfall in any particular period before sampling, because there is a limit to the amount of water that the surface of a plant can hold, so that rain falling after this limit is reached can cause no further increase, and because the persistence of surface moisture in the afternoon after rainfall earlier in the day must depend on temperature and humidity conditions during the morning. Also the surface wetting may be caused by dew. This is illustrated by the fact that the samples were recorded as being damp on 4 days when there had been no rainfall for many hours before the time of sampling. Partial regression coefficients of water-content on rainfall during the day of sampling between 9 a.m. and the time when the samples were cut, fitted in addition to the time, accumulated rainfall, and temperature terms, are given in Table 3.

TABLE 3. *Partial Regression Coefficients of Water-content, (per cent. of fresh weight) on Rainfall (inches) between 9 a.m. and the Time of Sampling*

	Stems		
	Basal 6 in.	*Rest*	*Ear*
Wheat . .	1·5±1·18	2·0±1·79	2·4±0·97
Barley . .	2·4±1·21	4·1±1·47	2·5±0·58

Though some of the coefficients were significant, the inclusion of the second rainfall term did not reduce the residual variance between sampling times in any of the six cases tested. It is of interest that the coefficients were greater for barley straw than for wheat straw, a similar result to that shown by the regressions on accumulated rainfall (Table 2).

This analysis serves merely to confirm the *a priori* expectation that low water-content, and consequently a greater probability of fire-risk, occurs after periods of low rainfall on days of high maximum temperature, and that the temporary presence of surface moisture may cause a large increase in apparent water-content. The most interesting result is the insensitivity of the water-content of oat straw to rainfall and temperature, and the higher sensitivity of the water-content of barley straw compared with wheat straw. This implies that when conditions favour a decline in water-content, that of barley will fall more rapidly to the critical value for inflammability than that of the other crops, so that there is a greater likelihood of a sudden, possibly temporary, development of a fire-risk with barley than with the other crops.

Regression equations computed from the data of a single abnormal season cannot safely be used to predict what would happen in other seasons, but the magnitude of the rainfall coefficients given in Table 2 shows that the variation in water-content at corresponding dates near to harvest in different years is likely to be very wide. For example, if

the July rainfall had the average value of 2·7 in. instead of the 5·4 in. recorded in 1941, the water-content of the upper part of barley shoots at the end of July would have been 27 per cent. lower, i.e. about 45 per cent. instead of 72 per cent.; for wheat the corresponding value would have been 54 instead of 70.

Summary

1. Barley crops growing in the field became inflammable, in the sense that a fire continued to spread and did not die out spontaneously, when the water-content of the straw fell below about 30 per cent. of fresh weight.

2. Laboratory tests on isolated barley and wheat straws showed that a flame was propagated indefinitely along a straw when its water-content was lower than about 30 per cent. In barley, a node acted as a barrier to the passage of flame along an isolated stem when the water-content was above 25 per cent.

3. Measurements of the changes during ripening in the water-content of oats, wheat, and barley crops were made in 1941, an abnormally wet season. The water-content of oats and wheat straw never fell below the critical value for inflammability, that of barley straw fell to the critical value only when the crop was left standing for about 2 weeks after it was dead ripe. It is suggested that delay in harvest after the stage when the crop becomes fit for cutting is probably the chief source of fire-risk.

4. A multiple regression on time, accumulated rainfall, and maximum daily temperature accounted for 50–80 per cent. of the variance between sampling times in the water-content of wheat and barley straw. Variation in the water-content of oat straw was apparently not dependent on rainfall. The water-content of barley straw was more sensitive to rainfall and temperature than that of wheat straw. Most of the positive deviations of observed values of water-content from values calculated from the regression equations occurred on days when surface moisture was present in the plants.

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REFERENCE

D. J. WATSON and E. C. D. BAPTISTE, Ann. Bot., 1938, N.S. **2**, 437–80.

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MILK PRODUCTION OF EGYPTIAN SHEEP

I. SIRRY, A. M. EL-SOKKARY, AND H. A. HASSAN

(*Dairy Department, Faculty of Agriculture, Fouad I University, Cairo*)

WITH PLATE 8

THE bulk of Egypt's milk-supply is provided by buffaloes and cows, sheep's milk constituting only a small fraction of the total. This, however, is mainly due to the low milk yield compared with that given by sheep in other countries where sheep's milk is the main source of the dairy industry. In spite of this fact, most Egyptian farmers keep a fair number of sheep, either for their mutton, wool, or milk. Also a good number of nomadic tribes own flocks, the milk of which is either consumed liquid or made into soft cheese.

In the absence of data concerning Egyptian sheep's milk production, this study which was carried out with the two most popular breeds, the Rahmani and Ausimi, is intended to give sheep breeders the necessary basic information to enable the work of improvement to be begun.

Experimental

The flock of the Faculty of Agriculture at Giza consists of two breeds of sheep. The Rahmani breed is popular in Egypt, particularly to the north of the Nile Delta and in Behera province. The fleece, head, and legs are brown, and some animals have no external ears. Rams have long twisted horns, but ewes are hornless. The average weight is about 160 lb. for adults with a large fat-tail, which is rectangular in shape extending below the hock joint and ending in a big knot (Plate 8, fig. 1). The Ausimi is another popular breed particularly in Giza province. It is white with a brownish head. Rams have long spiral-shaped horns, but ewes are hornless. It has a round fat-tail with a long thin end. The average weight for adult animals is about 120 lb. (Plate 8, fig. 2).

During the season of 1947–8, when this work was carried out, 80 Ausimi and 32 Rahmani ewes of the above flock lambed. Of these, 8 Ausimi and 6 Rahmani ewes were selected at random and milked 7 days after lambing (Group I). Milking continued until the end of lactation. Their lambs were fed artificially on buffalo milk while the rest of the ewes suckled their lambs for 3 months. All lambs were weaned on 2.3.48. Of the ewes which had suckled their lambs only 3 Ausimi and 10 Rahmani were still in milk after weaning and these were therefore hand-milked until they eventually went dry (Group II). Of the ewes in group I, 5 Ausimi and 1 Rahmani were dry by 2.3.48, so that the total numbers in milk from this date onwards were 6 Ausimi and 15 Rahmani. These details are given in Table 1.

The ewes were hand-milked once daily at 8 a.m. and the yield was recorded for each animal in millilitres.

The statistical treatment of these data, as calculated by the *t* test to show the significance of differences between the various yields [1], is given in Tables 2 and 3.

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TABLE 1. *Distribution of Ewes in the Flock*

Total number and breed	*Number of ewes (% in parentheses) which were:* (1) *Milked after lambing*	(2) *Milked after weaning*	(3) *Not milked*	(4) *Dry by 2.3.48 from col. 1*	(5) *Still in milk*	(6) *Total no. of ewes dry on 2.3.48*
80 Ausimi . .	8 (10)	3 (3·8)	69 (86·2)	5 (6·3)	6 (7·5)	74 (92·5)
32 Rahmani .	6 (18·8)	10 (31·2)	16 (50)	1 (3·1)	15 (46·9)	17 (53·1)

Daily samples were taken from the well-mixed bulk milk of the flock, and analyses carried out to determine the specific gravity, acidity, and fat-content. Chemical analysis was begun on the daily samples within 2 hours of milking. During the 6 months of the experiment 190 samples were analysed.

The flock grazed in the fields from which crops were removed, an additional ration of barley and clover (Berseem) hay being fed. This lasted from the beginning of lambing, about the end of October, to December 1, when green feeding on *Trifolium Alexandrinum* (Berseem or Egyptian clover) started. No additional feed was given during this latter period.

Methods of analysis.—Specific gravity was estimated by an accurate Quevenne lactometer at 60° F. Fat was determined by the original Gerber method, and acidity by titrating 10 ml. of milk with N/9 solution of sodium hydroxide using 0·5 per cent. phenophthalein solution as indicator, the value being calculated as percentage lactic acid.

Discussion of Results

Milk production.—The data obtained in the experiment for both breeds of sheep are summarized in Table 2.

TABLE 2. *Milk Yields of the Two Breeds*

Group	*No. and breed of ewes*	*Av. no. days milked*	*Av. daily yield, ml.*	*Range of total yield, litres*	*Mean total milk yield, litres*	*Significance*
I. Milking begun 7th day after lambing .	6 Rahmani	177·5	392	24–85	47·36±9·425	Sig.
	8 Ausimi	114	177	5–57	21·60±6·415	
	Difference	..	215	..	25·76	
II. Milking begun after weaning (89–129 days after lambing)	10 Rahmani	71·7	181	1–50	16·22±5·394	Not sig.
	3 Ausimi	69	146	3–25	11·54±6·397	
	Difference	..	35	..	4·68	

Total lactation yield.—The milk yields of the ewes in the first group indicate the general capabilities of the two breeds and show that the Rahmani is a somewhat better milker than the Ausimi, the actual difference being 25·7 litres, which is statistically significant. There was, however, a wide variation in the lactation yields of both breeds. The maximum yield for either breed was 85 litres given by a Rahmani ewe. This ewe was unfortunately seriously injured during the experiment before completing her lactation and had to be withdrawn. Had this not occurred, a much higher yield and longer lactation might have been obtained, a fact which indicates the possibilities of finding some good milkers among Egyptian sheep.

Milk yield of ewes after suckling lambs.—The data for the ewes in the second group of the experiment are given in the bottom half of Table 2. These ewes did not start milking until at least 3 months after lambing (Rahmani 101–129 days, Ausimi 89–112 days), the lambs being weaned on 2.3.48. The ewes (10 Rahmani and 3 Ausimi) continued to milk for approximately 70 days and though the difference in yield (4·68 litres) is small the figures tend to confirm those for the first group, namely, that the Rahmani ewes are heavier and more persistent milkers than the Ausimi. These figures are not, however, significant and there was wide variation in the yields for both breeds.

Average daily yield.—The difference between the breeds was 215 ml. for the ewes in group I, which is less than the amount sufficient for the suckling lamb. Rahmani ewes varied from 158 to 784 ml. and Ausimi ewes from 110 to 290 ml.

Maximum daily yield.—The highest yield given by a Rahmani ewe was 1·150 litres, that for an Ausimi ewe being 885 ml. The maximum yield was reached on the 9th–11th day after lambing, with the exception of one ewe (no. 69) which reached her peak on the 20th day, and gave the highest total yield. Barnicoat [2] states that the peak milk yield is reached within 2–5 weeks, the average daily yield of 60 ewes in his trial being 53 oz. (= 1·514 litres approx.).

Length of lactation.—Table 2 shows that the Rahmani ewes milked for almost 64 days longer than the Ausimi. Moreover, this breed appears to be more persistent in that 31 per cent. of the total flock were still in milk after weaning their lambs on 2.3.48, compared with 3·8 per cent. in the case of the Ausimi; and the total number of ewes in milk after that date (including those milked from the beginning of their lactation) was 47 per cent. of Rahmani, and 7·5 per cent. of Ausimi ewes (see Table 1). The range in length of lactation also varied with the breeds. Rahmani ewes ranged from 150 to 259 days and Ausimi ewes from 31 to 251 days.

Improvement in milk yield.—The necessity for improvement is, therefore, obvious from two points of view. The first is to obtain sufficient milk for the lambs and thus improve mutton production; the second is to establish a successful industry of sheep's milk products, of which the soft cheese is the most popular in the country. Moreover, Egypt imports an increasing amount of Kascavalli and Roquefort cheeses which are made of this type of milk. Fortunately, the success of such improvement seems to be within reach owing to the presence of some individuals with

a comparatively high yielding capacity. Cross-breeding with imported milk breeds may, therefore, be a good scheme if carefully performed and accompanied by selection. In Romania [3], where the sheep are kept mainly for milk and where a successful dairy industry has been established, the average yield is 380 kg. but only 50 kg. of this total is available for manufacture, the rest being suckled by the lamb. This production, however, is not exceptionally high compared with breeds in other countries. Schmidt [4] states that a yield of 600 kg. per head is not difficult to obtain in Germany, and he also states that the yield of East Friesian milk sheep may be as much as 1,400 kg. (1 kg. = 2·2 lb.).

The yield of Sardinian ewes [5], as a result of selection based on performance tests, has been increased to an appreciable extent; the maximum yield recorded is 460 kg. in a lactation period of 339 days, and the average lactation aimed at is 300–50 kg. In Palestine [6], cross-breeding with imported breeds was tried and given up in favour of the improvement of the 'Awasi' by selection. Average yields of 213 kg. for 37 flocks had been attained, the record yield being 489 kg.

On the other hand, much lower yields have been reported in other localities, i.e. in Azerbaidjan [7] 25–90 kg. in 4½–7 months, in Sicily [8] 74–123 kg. according to number of previous lactations, in Cyprus [9] 80·4 kg., and in the Croatian Coastal Zone [10] 61·4 kg. in 129 days. The maximum yield attained in the last zone was 77·5 kg. in 140 days.

Comparison of yields of ewes in milk after 2.3.48.—The yields of 8 of the 14 ewes of both breeds in the first group and 13 ewes which began milking after weaning are compared in Table 3, the yields referring to the same period, i.e. from 2.3.48 to the end of lactation. This table shows that the average yields during this period were 11·567 litres for the first group, and 15·144 litres for the second. This leads to the conclusion that the suckling of the ewe has a beneficial effect upon her milk production, and agrees with the results of Kirsch [11], although these yields are not statistically significant.

TABLE 3. *Yield of Ewes Milked after 2.3.48*

Group	*No. of ewes in group*	*Av. number of days in milk after 2.3.48*	*Av. daily yield, ml.*	*Total yield from 2.3.48 until dry, litres*	*Significance*
Milked after lambing .	8 (3 A+5 R)	77	123	11·56±4·185	
Milked after weaning. .	13 (3 A+10 R)	71	167	15·14±3·554	
	Difference	..	..	3·58	Not significant

Daily milk analysis.—The data obtained from the analysis of the daily samples of milk give valuable information as regards the most commonly

determined properties for bulked milk, namely, specific gravity, acidity, and fat; these are given in Table 4.

TABLE 4. *Summary of Results for the Daily Analysis of Mixed Milk (190 samples)*

	Sp. Gr.	*Acidity %*	*Fat %*
Minimum .	1·0326	0·160	5·05
Maximum .	1·0422	0·270	10·00
Mean . .	1·0356	0·229	7·87

Comparing these data with the results of other investigators, it is seen that the mean fat-content for the present study is lower than that given by Besana [12], i.e. 8·92 per cent. On the other hand, it is higher than those obtained by Barnicoat [2] and Zdanovski [13], i.e. 6·15 and 6·91 per cent. respectively. The last-mentioned workers found that the average value for specific gravity was 1·0388, ranging from 1·0370 to 1·0416, this being a higher value for the average and rather smaller range of variation than in the present study. Schneck and Plottke [14] gave results showing a range of 1·0295–1·0450.

The acidity of sheep's milk as shown by this study is of much higher value than that usually experienced with cows' milk. Matheson [15] states that ewes' milk always gives acidity tests higher than 0·2 per cent. as lactic acid.

Summary

The object of this work was to study the milk production of two breeds of Egyptian sheep, namely, Rahmani and Ausimi. The data obtained show that the milk yield of both breeds is comparatively low. The average lactation milk yield for the Rahmani was 47·4 litres, whilst that of the Ausimi was 21·6 litres, with average lactation periods of 178 and 114 days respectively. The maximum yield, given by a Rahmani ewe, was 85 litres. A comparison of the milk yield for the last 70 days of lactation of ewes of both breeds milked after weaning with that of ewes which had been milked from the beginning of lactation indicated that suckling had a beneficial effect on milk yield, the yield of the former being 3·57 litres more during this period. This difference was, however, not statistically significant.

Daily samples of the mixed milk were analysed for specific gravity, acidity, and fat content. The respective averages throughout the season were: 1·0356, 0·229, and 7·87 per cent.

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REFERENCES

1. R. A. Fisher, Statistical Methods for Research Workers, 1936.
2. C. R. Barnicoat, Proc. N.Z. Soc. Anim. Prod., 1943, pp. 56–8.
3. H. Schäfer, Dairy Sci. Abstr., 1944, **6**, 68.
4. H. W. Schmidt, ibid., 1945, **7**, 5.
5. G. Reinboth, ibid., 1939, **1**, 3.
6. (Mimeograph), Jewish Sheep Breeders' Association in Palestine. Animal Breeding Abstracts, 1948, **16**, 33.
7. F. A. Melikov and U. Kassoumov, Dairy Sci. Abstr., 1942, **4**, 67.
8. G. Montanaro, ibid., 1941, **2**, 267.
9. J. P. Maule, Ann. Rept. Dept. Agric., Cyprus, 1938.
10. N. Zdanovski, Poljodj. Znanstv. Smotra (Zagreb), 1942, No. 6, 55–70.
11. W. Kirsch, Dairy Sci. Abstr., 1944, **6**, 1.
12. C. Besana, Analyst, 1893, **18**, 248.
13. N. Zdanovski, Poljopr. Znanstv. Smotra (Zagreb), 1946, No. 9, 57–88.
14. A. Schneck and H. Plottke, Vorratspfl. u., Lebensmittel-Forsch., 1940, **3**, 349–64.
15. K. J. Matheson, Dept. Agric. U.S.A., 1921, Bull. No. 970.

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FIG. 1. The Rahmani breed

FIG. 2. The Ausimi breed

FIELD EXPERIMENTS IN SELECTIVE WEED CONTROL BY PLANT-GROWTH REGULATORS

II. THE EFFECT OF PLANT-GROWTH REGULATORS UPON CEREAL CROPS

W. G. TEMPLEMAN AND D. J. HALLIDAY

Introduction.—In a previous paper [29] the authors described experiments conducted in 1943–5 on weed control in cereal crops. These experiments showed that *Sinapis arvensis* (Yellow Charlock), *Thlaspi arvense* (Pennycress), *Chenopodium album* (Fat Hen), and *Raphanus raphanistrum* (White Charlock, Wild Radish, or Runch) were readily controlled by the sodium salt of 4-chloro-2-methylphenoxyacetic acid (M.C.P.A.) applied at 2 lb. of active material per acre, and that many other weeds were killed or seriously checked by M.C.P.A. applied at higher rates. In the present paper the authors discuss the effect of such applications on the yield and quality of grain from treated crops.

Yield Increases due to Weed Control

Agriculturists and economists have been cautious in estimating the magnitude of yield increases which may be expected after effective weed control. As a result of numerous experiments in Norway from 1916 to 1923, Korsmo [30] was able to demonstrate that grain yields from spring cereals, kept clean by hand-weeding or by sulphuric-acid spraying, averaged 24 per cent. higher than those from untreated crops. Applying these results to Germany, he deduced that weed-control measures, if adopted throughout the country, would increase the average yields of wheat, barley, and oats by 2·5, 3·5, and 3·4 cwt. per acre respectively. In Canada, where weeds are probably responsible for an overall grain loss of 16–20 per cent. [31], Godel [32] showed that, by sulphuric-acid spraying at the 2–3 leaf stage, wheat yields could be improved by 2·9–3·3 cwt. per acre.

Recent experience indicates that similar results may be achieved at less cost and without harm to operators or machinery by means of plant-growth regulators. In Great Britain, where white charlock is probably the most aggressive weed, Blackman [11] reports an average grain increase of 22 per cent. from three years' experiments with M.C.P.A. and D.C.P.A. (2, 4-dichlorophenoxyacetic acid). In some cases barley yields were increased by 90 per cent. In Canada [33] 1½ million extra bushels were produced in 1947 from 500,000 acres of wheat treated with D.C.P.A.; in 1948 4 million acres were so treated. In Colorado, U.S.A., barley and wheat, cleared of bindweed and poverty weed (Iva sp.), yielded an additional 10–20 bushels per acre. In Sweden [34], spraying with D.C.P.A. sodium salt at 0·15 per cent. concentration increased the yield of Kenia barley, previously infested with yellow charlock, by 21 per cent. from 28·9 to 35·0 cwt. per acre; whilst M.C.P.A. ('Agroxone') at 0·2 per cent. concentration gave a further increase to 38·0 cwt. per acre.

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Yield increases obtained in early experiments at Jealott's Hill [29] were equally encouraging. In 1944 spraying winter oats with 1 lb. M.C.P.A. per acre to eradicate corn buttercup resulted in a statistically significant gain over the controls of 3·7 cwt. per acre (significant difference 2·8 cwt.). Similar results were obtained in experiments on winter wheat and spring barley and oats at various centres in south and east England (Tables 1, 2, 3).

Although the increase in yield that may be expected as a result of weed control is clearly dependent upon the initial degree of weed infestation, on the supply of moisture and plant nutrients in the soil and on other local factors, a return of 3 cwt. grain per acre is not unreasonable under average conditions.

TABLE 1. *Pre-emergence Application of M.C.P.A.: Effect on Crop Yield 1944–5*

Crop	*Centre*	*M.C.P.A. dust lb./acre*	*Application date*	*Weed 'kill' (per cent.)*	*Grain yield (cwt./acre)*	*Sig. diff. (cwt./acre)*
Spring Barley (1944)	Mitcheldever	0	At sowing	0	27·7	N.S.
		1		78	28·8	
		2		80	30·1	
		4		99	28·9	
	Watlington	0	At sowing	0	8·1	3·4
		1		89	18·3	
		2		93	16·5	
		4		97	16·5	
	Shillingford	0	At sowing	0	11·1	3·8
		1		76	21·2	
		2		93	20·0	
		4		95	21·4	
(1945)	East Ilsley	0	9 days after sowing	0	10·1	N.S.
		1		56	12·3	
		2		78	12·0	
		4		86	11·6	
	Holyport	0	3 weeks after sowing	0	11·5	2·3
		1		63	14·0	
		2		78	15·8	
		4		93	14·6	

N.S. = difference not significant.

The Effect of M.C.P.A. on the Yield from Clean Crops

Concurrently with the work on weed control, further experiments were undertaken at Jealott's Hill to study the effect on clean cereal crops of plant-growth regulators at rates exceeding those which would normally be required for weed control (Table 4). It soon became evident that applications of M.C.P.A. at 4 or more lb./acre at seeding time were liable, under certain conditions, to damage the cereal crop and reduce the yield, barley being more susceptible than oats or wheat. The heavier rates were therefore reserved for application after the crop had become established.

With a single exception, the yield of *spring oats* was not significantly

TABLE 2. *Post-emergence Application of M.C.P.A.: Effect on Crop Yield 1944*

Crop and centre	Chief weed and date of applying M.C.P.A.	M.C.P.A. treatment				
			Dust		Spray	
		Rate (lb./acre)	Grain yield (cwt./acre)	Weed 'kill' (per cent.)	Grain yield (cwt./acre)	Weed 'kill' (per cent.)
Oats (East Ilsley)	*Sinapis arvensis* (Mar. 11)	0	17·4	0	17·4	0
		½	17·8	33	17·1	85
		1	17·2	47	19·6	99
		2	17·9	76	18·4	100
(Shillingford)	*Raphanus raphanistrum* (Apr. 21)	0	12·1	0	12·1	0
		½	14·5	31	17·2	96
		1	15·6	49	19·2	100
		2	16·6	85	16·0	99
		4	16·4	92	15·8	100
Barley (Mitcheldever)	*Sinapis arvensis* (Apr. 27)	0	32·0	0	32·0	0
		½	32·3	60	31·4	100
		1	31·5	84	29·9	100
		2	30·5	98	32·1	100
(Watlington)	*Raphanus raphanistrum* (Apr. 19)	0	4·8	0	4·8	0
		½	9·4	21	14·9	78
		1	8·3	15	12·8	93
		2	11·4	60	12·0	98
	(May 12–13)	0	8·4	0	8·4	0
		1	13·4	50	13·7	27
		2	14·7	24	13·1	87
		4	13·0	30	14·6	97
(Shillingford)	(Apr. 28)	0	12·5	0	..	..
		1	14·7	90	..	..
		2	15·2	100	..	..
		4	18·3	100	..	..

Sig. diffs.: Barley (Watlington): 4·4 cwt./acre (4-leaf); 2·5 cwt./acre (in flower).
Barley (Shillingford): 1·7 cwt./acre.
Oats (Shillingford): treatment differences not significant, but control significantly less than mean of all other plots.
Oats (East Ilsley): differences not significant.
Barley (Mitcheldever): differences not significant.

The weed density on the untreated plots ranged from 13 to 22 plants per square foot.

altered by dust or spray applications of M.C.P.A. at rates up to 16 lb./acre when 6–8 in. high. The exception occurred in 1945, when spraying at the 8-lb. rate reduced the grain yield by 2·4 cwt./acre. In this case the 16-lb. rate caused no such reduction, nor was the result repeated in a similar experiment in 1947. Spraying at 16 lb./acre at a later stage of growth, when the crop was 18–22 in. high, did, however, cause a significant reduction in yield.

The yield of *winter oats* was also not significantly altered by applications of M.C.P.A. at rates up to 16 lb./acre when 3–8 in. high, but yields after application at the 10–12-in. stage were significantly lower than after application at the 3–4-in. stage. Although the individual differences in the 1945 experiment were not significant, the average of all treatments at the 8-in. stage produced a significantly lower yield than similar treatments at the 3–4-in. stage.

TABLE 3. *Post-emergence Application of M.C.P.A.: Effect on Crop Yield 1945*

Crop and centre	Chief weeds present	M.C.P.A. treatment		Grain yield (cwt./acre)		
		Rate (lb./acre)	Date applied	Dust treatment	Spray treatment	Sig. diff.
Spring barley (Holyport)	*Chrysanthemum segetum*	0	..	10·0	10·0	2·0
		1	May 29	12·5	10·2	
		1	June 13	13·3	12·9	
		2	May 29	11·0	12·4	
		2	June 13	12·8	12·8	
		4	May 29	13·5	12·3	
		4	June 13	12·7	9·9	
Winter wheat (Holyport)	*Ranunculus* spp. *Lathyrus aphaca* *Sonchus oleracea* *Anagallis arvensis* *Polygonum convulvulus* *Cerastium vulgatum*	0	..	12·4	12·4	3·2
		1	Mar. 22	13·1	11·4	
		2	,,	17·1	14·0	
		4	,,	12·0	12·3	

Grain yields were calculated from 3 single square-yard samples taken at random from each 1/200-acre plot, i.e. 12 square-yard samples per individual treatment and 24 square-yard samples for the untreated controls. Significant differences relate to differences between treatments. Significant differences between treatments and controls are thus smaller by approximately 15 per cent.

Spring barley was unaffected by M.C.P.A. at rates up to 8 lb./acre applied in May or early June at any stage from 4 to 24 in. high, but the 16-lb./acre rate caused a significant reduction in yield.

Winter wheat was unaffected by dust applications of M.C.P.A. at rates up to 16 lb./acre, whether applied in March, April, or May. In 1945, an early year, spraying at the 16-lb./acre rate caused some damage, particularly to a crop 30 in. high at the time of application. Even 4 lb. M.C.P.A. per acre sprayed at the latter stage apparently caused a significant reduction in yield, but the results were inconsistent, since the 8-lb./acre rate caused no such reduction. When the experiment was repeated in 1947, the crop was only 9 in. high when sprayed on May 14, and not even 16 lb. M.C.P.A. per acre caused any significant reduction in yield.

Abnormalities caused by Plant-growth Regulators

All the spray applications of M.C.P.A. at 8 or 16 lb./acre caused considerable scorching of the leaves, this being more marked the later the time of application. Dusts, even at the highest rates, caused no appreciable scorching. In a very few cases some malformation of barley ears was observed, in which the awns were not fully withdrawn from the sheath. This was quite distinct from the yawning spikelet type of malformation prevalent in East Anglia in 1947 and attributed to unusual weather at a critical stage of flower development [35]. Abnormalities,

TABLE 4. *Yields of Clean* Cereal Crops treated with M.C.P.A., Jealott's Hill, 1943–7*

Crop	Date M.C.P.A. applied	Grain yield (cwt./acre)									
		Rate of M.C.P.A. application (lb./acre)									
		Dust treatment					Spray treatments				
		0	2	4	8	16	0	2	4	8	16
Spring oats											
1943	May 7 (crop 10–12 in. high)	20·1	17·7	21·1	..	..	20·1	21·8	20·6	..	..
1944	(at seeding)	21·8	21·6	18·5†	..	..	..	..	..	..	..
	(crop 6–8 in. high)	21·8	22·8	22·8	..	..	..	..	..	..	..
1945	Mar. 27 (pre-emergence)	17·4	18·6	16·2	18·0	..	17·4	17·1	18·4	19·0	..
	May 1 (crop 6 in. high)	17·4	..	15·3	15·8	16·4	17·4	..	16·1	15·0†	17·9
	June 5 (crop 18–22 in. high)	17·4	..	15·6	16·5	15·6	17·4	..	18·0	15·5	14·3†
1947	June 12 (crop 8 in. high)	..	..	..	..	..	8·8	10·3	8·2	9·4	8·4
Winter oats											
1945	Mar. 20 (crop 3–4 in. high)	24·9	..	27·1	31·2	28·3	24·9	..	29·0	28·4	29·5
	Apr. 17 (crop 8 in. high)	24·9	..	25·3	24·6	24·7	24·9	..	26·5	23·7	21·3
	May 28 (crop 10–12 in. high)	24·9	..	22·8	22·9	22·2	24·9	..	23·8	21·7	21·7
Barley											
1943	May 25 (crop 15–18 in. high)	..	..	..	..	..	23·5	22·9	21·7	..	..
1944	(at seeding)	30·3	22·9†	20·2†	..	..	..	..	..	..	..
	(crop 6–8 in. high)	30·3	30·2	25·1	..	..	..	..	..	..	..
1945	Apr. 12 (pre-emergence)	18·2	19·3	..	..	..	18·2	19·9	..	..	..
	May 10 (crop 4–6 in. high)	18·2	19·6	17·7	20·2	..	18·2	17·7	18·8	17·6	..
	June 11 (crop 24 in. high)	18·2	..	17·7	18·8	17·6	18·2	..	18·2	18·4	15·3†
1947	June 17 (crop 7 in. high)	..	..	..	..	..	6·3	6·4	5·9	5·3	4·0†
Wheat											
1945	Mar. 20 (crop 3–4 in. high)	28·6	..	30·1	29·5	28·0	28·6	..	25·0	29·8	24·7†
	Apr. 17 (crop 8–10 in. high)	28·6	..	26·8	26·5	26·3	28·6	..	28·7	26·9	24·1†
	May 28 (crop 30 in. high)	28·6	..	28·4	28·6	30·2	28·6	..	22·8†	28·0	18·8†
1947	May 14 (crop 9 in. high)	..	..	..	..	..	13·6	13·4	13·3	13·5	12·4

* All crops were reasonably free from weeds except the winter oats where certain increases in yield from early applications may be explained by the weed control obtained.

† Significantly lower than yield without M.C.P.A. treatment.

consisting of twisting or breaking of the rachis due to partial or obstructed emergence of the ear from the sheath and a tendency for sterile florets to become fertile, were noted in 11 of the 63 barley extension trials conducted in 1945, but in only 4 of these was the proportion of affected ears considerable. Abed Kenia barley appeared to be more susceptible than other varieties. Wheat and oats were unaffected. Ear malformations in general did not reduce grain yields nor lower viability. Under commercial conditions in 1948, for example, damage to barley occurred in only 7 of an estimated total of 70,000 cases where M.C.P.A. was applied

[28]. Blackman, Holly, and Roberts [36] report that in their experiments depressions in yield were rare and occurred only where M.C.P.A. sprays were applied at concentrations greater than 0·2 per cent. They suggest that the comparative absence of physiological disturbances may be due to varietal differences or to the lower temperatures encountered in England than elsewhere in Europe. A further explanation may be that the M.C.P.A. sodium salt, which is the most commonly used hormone weedkiller in Great Britain, is less liable to cause damage than the ester formulations of D.C.P.A., which have been tested elsewhere. In Sweden, for example, where comparative tests have recently been conducted by Hagsand and Väärtnöu [37], M.C.P.A. is officially recommended for use on cereals, linseed, and flax, but the use of D.C.P.A. esters is not advised [38]. In Holland, too, the use of M.C.P.A. and D.C.P.A. salts is officially recommended for winter cereals, but M.C.P.A. alone is considered safe for use on spring cereals as the latter are more susceptible to damage by growth-regulators [39].

Osvald and Åberg [40] in Sweden and Loomis [41] in America conclude that the resistance of cereals to hormone weedkillers is temporarily lowered when the plants are tillering, i.e. at the 3–5 leaf stage 2–4 weeks after emergence, and again at the late boot stage just before heading. It is suggested that the flower and perhaps tiller meristems pass through short periods of sensitivity. Our own experience confirms that most damage occurs when cereals are sprayed too soon after sowing or after they have passed 2 ft. in height. In a normal year under English conditions winter cereals are best sprayed in late March or early April, and spring cereals in early May.

Effect on Germination

When malformed barley ears were noticed, it was at first feared that hormone weedkillers might adversely affect the germinative quality of seed-grain. Initial tests at Jealott's Hill in 1945 soon showed, however, that there was no significant difference in the percentage germination of grain from malformed and from normal ears. These tests were made approximately 6 weeks after harvesting (Table 5). Later observations by Hagsand and Väärtnöu [37] confirm this conclusion and indicate that M.C.P.A. or D.C.P.A. applications to spring

TABLE 5. *Comparison of Grain from Normal and Malformed Ears of Abed Kenia Barley treated with M.C.P.A.*

M.C.P.A. applied (*lb./acre*)	*Germination per cent.*		*1,000-corn weight* (*gm.*)	
	Normal	*Malformed*	*Normal*	*Malformed*
0	99·2	..	43·5	..
1	99·2	99·8	40·8	39·8
1½	99·2	99·0	37·7	36·2
2	99·5	99·5	41·2	39·6
3	99·0	99·5	40·5	38·6
4	99·2	99·5	41·5	39·2

cereals within 3–4 weeks after emergence, though occasionally causing a proportion of malformed ears, have no effect on the germination of the grain. Hagsand and Väärtnöu found no definite differences in susceptibility between the several varieties of spring wheat, barley, and oats which they tested, such small differences as occurred being entirely attributable to earliness or lateness. Spraying at a late stage of development sometimes caused a decrease in 1,000-corn weight and a decrease in germination.

Comparison between M.C.P.A. and D.C.P.A.

Direct comparison of the effects of M.C.P.A. and D.C.P.A. sodium salts on clean cereal crops was undertaken at Jealott's Hill in 1943 and again in 1947 (Table 6). In 1943 D.C.P.A. was accidentally applied at heavier rates than M.C.P.A. and, although there was an indication that D.C.P.A. at the same rates might result in lower grain yields than M.C.P.A., the statistical significance of this difference was doubtful (the average of $3\frac{1}{4}$ and $6\frac{1}{2}$ lb. D.C.P.A. per acre just differed from the average of 4 and 6 lb. M.C.P.A. per acre at the 5 per cent. significance

TABLE 6. *Comparison of Yields of Clean Cereal Crops treated with M.C.P.A. and D.C.P.A., Jealott's Hill, 1943–7*

Crop	*Application date*	*Application rate (lb. acid equiv. per acre)*	*Grain yield (cwt./acre)*				*Sig. diff.*
			With M.C.P.A.		*With D.C.P.A.*		
			Dust	*Spray*	*Dust*	*Spray*	
Spring oats	May 7	2	17·7	21·8	..	..	
1943		$3\frac{1}{4}$	..	..	20·9	19·6	
		4	21·1	20·6	..	..	4·6
		6	23·1	22·3	..	..	
		$6\frac{1}{2}$	..	..	18·2	18·2	
		$9\frac{3}{4}$	..	..	15·5	13·2	
1947	June 12	2	..	10·3	..	9·6	
		4	..	8·2	..	8·5	1·7
		8	..	9·4	..	8·5	
		16	..	8·4	..	6·8	
Spring barley	May 25	2	..	22·9	..	..	
1943		$3\frac{1}{4}$	..	..	..	20·6	
		4	..	21·7	..	..	2·7
		6	..	22·5	..	..	
		$6\frac{1}{2}$	..	..	..	19·7	
		$9\frac{3}{4}$	..	..	..	18·8	
1947	June 17	2	..	6·4	..	6·4	
		4	..	5·9	..	7·0	1·4
		8	..	5·3	..	6·4	
		16	..	4·0	..	5·8	
Wheat 1947	May 14	2	..	13·4	..	12·9	
		4	..	13·3	..	13·0	N.S.
		8	..	13·5	..	13·0	
		16	..	12·4	..	12·3	

level). The experiment was repeated in 1947 without any consistent differences being observed.

Summary

Evidence from various countries indicates that effective weed-control measures may increase average grain yields by approximately 3 cwt. per acre. In some instances weed control by M.C.P.A. increased yields by 7–10 cwt. per acre. Experiments on weed-free crops show that M.C.P.A. sodium salt may be applied as dust or spray at rates up to 8 lb. per acre to wheat, barley, and oats from 3 to 8 in. high without adversely affecting yields. Applications of 16 lb. per acre at this stage of growth did not generally reduce yields when given in dust form, but sprays sometimes caused damage. Applications at the time of sowing or when crops were more than 10 in. high also reduced yields in some cases. Occasional malformation of barley ears apparently had no effect on the germination of the grain. There was no consistent difference between the effects of the sodium salts of M.C.P.A. and D.C.P.A. applied at equivalent rates.

REFERENCES

(Earlier references are given at the end of Part I, pp. 29–30.)

29. W. G. Templeman and D. J. Halliday, Empire J. Expt. Agric., 1950, **18**, 19–30.
30. E. Korsmo, Umkräuter im Ackerbau der Neuzeit. Julius Springer, Berlin, 1930.
31. G. P. McRostie *et al.*, Canada Nat. Res. Counc., 1932, Rept. No. 27.
32. G. L. Godel, Proc. World's Grain Exhib. and Conf., Canada, 1933, **2**, 207–13.
33. N. E. Van Stone, Agric. Chem., 1948, **3** (4), 33–6, 79–81.
34. T. Denward and E. Åberg, Växtodling, 1947, (2), 259–80.
35. W. A. R. Dillon Weston, E. C. Large, and F. Earnshaw, J. Min. Agric., 1947, **54**, 417–21.
36. G. E. Blackman, K. Holly, and H. A. Roberts, Soc. Expt. Biol. Symposia (3), 1949, 283–317.
37. E. Hagsand and H. Väärtnöu, Växtodling, 1949, (4), 8–30.
38. Y. Gustafsson, G. Sundelin, E. Åberg *et al.*, Ogräsbekämpning med hormonderivat, Roy. Agric. Coll. Sweden and State Agric. Res. Stat. Stockholm, 1949.
39. Anonymous, Onkruidbestrijding met chemische middelen. Wageningen Plantenziektenkundige Dienst Verslag. en Meded. 1949, (111).
40. H. Osvald and E. Åberg, Växtodling, 1948, (3), 74–92.
41. W. E. Loomis, N. Central Weed Control Conference Res. Rept., 1949, p. 210.

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Note: In a Summary of their previous paper the authors stated that young seedlings of *Chrysanthemum segetum* (Corn Marigold) and *Viola tricolor* (Heartsease) were effectively controlled by M.C.P.A. at 4 lb. active material per acre. It should have been explained that successful control was achieved only when the weedkiller was applied to the soil before the young seedlings emerged and that in the case of *C. segetum* this result has not been repeated in later trials.

RECENT RESEARCH ON THE COCONUT PALM WITH SPECIAL REFERENCE TO CEYLON

REGINALD CHILD

(*Formerly Director, Coconut Research Scheme, Ceylon, now at the Tea Research Institute, Kericho, Kenya Colony*)

Introduction.—THE world area under the coconut palm is credibly estimated [1] at not less than 10 million acres, carrying some 500 m. bearing trees and producing annually an edible oil equivalent of about 3 m. tons. Prof. T. P. Hilditch [2] has stated that in Great Britain the pre-war consumption of fats supplied as such for edible purposes averaged about 40 lb. per head per annum; at this level the coconut palm may be reckoned to supply the fat-ration for just over 7 per cent. of the world's population now estimated by the Food and Agricultural Organization at about 2,300 m. Prof. Hilditch concluded that the main source of expansion in fat-supplies lies in extended development of the scientific cultivation of appropriate oil-bearing plants. The present article reviews recent research on the coconut palm, especially that carried out in Ceylon; it will be suggested that the extension of research and the wide application of present knowledge to existing coconut lands would result in an increase of world fat-supplies more certain and economical than the opening of new areas under annual crops.

Ninety per cent. of the world's exportable coconut products comes from five large producing areas: Indonesia, Philippines, Ceylon, Malaya, and Oceania. India, a large producer, consumes all its own production, and is now in fact a considerable net importer. In all these localities much *ad hoc* research has been carried out, mainly concerned with the empirical solution of local problems, and the published results of such work are widely diffused through a variety of journals all over the world, in scientific periodicals, reports of agricultural departments and research stations, planting-magazines, and the like.

Systematic long-range applied research on the crop is of recent origin. From about 1906 the palm has been studied—mostly from the standpoint of its physiology—in the Philippines; the well-known volume of Copeland [3] describes this work. Much information has come from the four stations of the Department of Agriculture, Madras [4, 5]. A Research Scheme with a full-time staff commenced work in Ceylon in 1933. In 1929 the Department of Agriculture, Straits Settlements and Federated Malay States, appointed a full-time officer for research on coconut products. Entomological work in Fiji has provided good examples of biological control, to which further reference will be made. Stations in Indonesia carried out much work on coconut palms and included one entirely devoted to the crop under Dr. P. L. M. Tammes.

Pests and Diseases

Insect pests.—As with many tropical crops, the earliest problems demanding attention related to pests and diseases. Lepesme noted in

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1947 [6] that 751 species of insects were on record as attacking or infesting the coconut palm; of these 278 or 37 per cent. are specific on palms, 165 or 22 per cent. are specific on *Cocos nucifera* L. Seventy-four, or over one-half, of the Cocos-specific insects are found in the Melanesian area, which Lepesme regards as supporting the hypothesis, argued by Beccari [7], Werth [8], and others, that the coconut palm had its original habitat in that region.

Of the 751, fortunately only a few are serious pests, and where these are not adequately controlled it is usually not because of lack of knowledge. For example, the control of the Black Beetle, *Oryctes rhinoceros* L. and other Oryctes spp., and that of the Red Weevil, *Rhyncophorus ferrugineus* Ol., are, as Baptist [9] has recently pointed out, matters of plant-sanitation; in the former the disposal of dead trees and all organic matter that can serve as breeding places; in the latter prompt attention to wounds and injuries which provide entry for the weevil.

The Coconut Scale, *Aspidiotus destructor*, was first described by Signoret in 1869 on material from Réunion. In India and Ceylon it rarely causes serious damage, being controlled by its natural enemies, particularly the small blue-black ladybird beetle, *Chilocorus nigritus* F. In some countries, notably Fiji, it became introduced without its natural enemies and caused serious losses; the study of its parasites and its ultimately successful control by the Coccinellid *Cryptognatha nodiceps* Mshl. are described by Taylor [10].

It is normally neither practicable nor economic to control coconut pests by the use of insecticides, except possibly on seedlings or young palms attacked by scale insects or caterpillars. Various species of caterpillar attack the coconut palm, some of them seriously, and it is with some of these that biological control has achieved striking results. The control of *Levuana iridescens* Baker, a moth confined to Fiji, by the introduced parasite *Bessa remota* Aldr. has become a classic example of this type of work. It was particularly remarkable in that a parasite of another genus was found to attack the genus Levuana [11]. (*B. remota* is a parasite of the Malayan coconut pest *Artona catoxantha* Hmps.)

A less well-known example is the partial control of the Black-headed Caterpillar, *Nephantis serinopa* Meyr., in the Eastern Province of Ceylon by the Eulophid parasite *Trichospilus pupivora* Ferr. The caterpillar came into prominence in this locality and along the Malabar coast of India about 1919, and much study was devoted to its natural parasites [12, 13]. In the wet zone of Ceylon natural control is largely due to *T. pupivora*; this parasite will not establish itself in the dry zone, but a measure of control has been achieved by the liberation at suitable times of large numbers of parasites bred at a departmental laboratory [9, 14].

Diseases.—In the main producing regions, the coconut palm is affected by few serious fungal, bacterial, or virus diseases, and there has been little recent work on them. Three diseases—or rather sets of symptoms—are selected for discussion here, since in the writer's opinion they all present outstanding problems for investigation. For other pathological conditions reference may be made to Briton-Jones [15].

Bud-rot.—True bud-rot is regarded as caused by the fungus *Phytophthera palmivora* Butler, which was recorded [16] on coconut, areca, and palmyra palms in Madras in 1906. Since then in most coconut-growing countries bud-rot due to Phytophthera spp. has been described, but it does not appear to be of extensive economic importance; in India it is only sporadic, and in Ceylon, Park and Fernando [17] describe it as of rare occurrence. Sharples [18] in 1924 asserted that no true fungal or bacterial bud-rot occurred in Malaya, but that the condition so called was the consequence of damage by lightning; any organisms isolated from dead specimens resulted from secondary infections. Altson [19] has more recently defended this thesis against the criticism of Briton-Jones [15].

Park and Fernando [17] pointed out that in Ceylon coconut palms are very subject to injury by lightning, and the present writer would agree with them that 'in well-grown coconuts more casualties are caused by lightning than by any other agency'. Attention may be drawn to the observations of Gadd [20] on lightning damage to tea and to shade trees grown in tea, which shows similar features to that on coconut palms. It would be of interest to follow up in some detail actual known examples of lightning strike and to define more closely the physiological effects on palms, especially in the frequent cases where death is delayed.

Tapering.—Briton-Jones [15, chap. iv] describes a condition known as 'tapering stem wilt', and refers to the picturesque name given in Jamaica, 'Pencil-point disease'. The characteristics of what is known in Ceylon as 'tapering disease' [21] are a diminution of the diameter of the trunk, with a corresponding dwindling of the size of the newly emerging fronds, until ultimately the palm dies. In many cases it is possible to refer these symptoms to fairly obvious cultural conditions whose effect in checking the growth and development of the palm is felt only after it has reached a certain stage; such are hard-pan, waterlogging, soil deficiencies, and senility [17]. There remain cases where such factors are not operative, and further study is needed. Investigations have recently been started under the Coconut Research Scheme, Ceylon, on the possibility of minor-element deficiencies [22], to which further reference will be made.

Nut-fall.—The coconut palm produces new flowering branches at approximately monthly intervals; the female flowers, relatively few in number, appear at the base of the panicle; above them are the numerous male flowers. From the emergence of the spadix to complete maturity of the fruit takes 12–13 months; at any one time, therefore, the palm is carrying 12 or more bunches at successive stages of development.

The fall of immature nuts within 2 months of the emergence of the spadix is a normal phenomenon, since far more female flowers are produced than the palm can bring to maturity. Gadd [23] quoted figures of 29–35 per cent. of female flowers reaching maturity, and similar figures were obtained in the Ceylon Coconut Research Scheme's principal manurial experiment [24]. On very poor soil, much higher percentages of set from smaller initial numbers of female flowers per spadix were recorded. Fertilizer applications which increased the total crop did so

by increasing in greater proportion the initial number of female flowers; the percentage maturing was decreased [25].

The fall of immature nuts at a later stage often causes considerable losses of crop, which should be preventable; nut-fall at 3 or 4 months' development is common. It is often heavy after unusually prolonged dry weather, and may especially occur with the onset of the first rains. Park and Fernando [17] therefore advocate measures aimed at improving the water-holding capacity of the soil. *Phytophthera palmivora* Butler is suspected of causing nut-fall, especially of nuts of full-size but of immature development (6–8 months). An obvious predisposing factor is weakness of the bunch stalks; a bunch of immature nuts may weigh over 50 lb., and actual breakage of the stalk may occur. For this reason, seednuts are selected from mother palms having short sturdy bunch stalks (*v.i.*).

An editorial in the *Tropical Agriculturist*, Ceylon, 1941 [26], describes recent observations on empirical treatments for nut-fall; no significant effects have been noted and an obvious field for investigation lies open; treatments with plant hormones might well be tried.

Genetics, Seed Selection, and Germination

The diploid chromosome number of *C. nucifera* L. $2n = 32$ has been reported by Santos [27] and by E. J. Janaki-Ammal [28]. The number of distinct varieties of the coconut palm has not been exactly determined, partly because of the difficulties involved with a plant of such wide distribution, and partly because of the lack of genetical purity due to natural cross-pollination. Almost all of the palms grown commercially are of ordinary tall varieties. Dwarf types have been grown on a limited plantation scale, especially in Malaya [29], but experience in Ceylon has not been favourable [30].

In the principal coconut-growing countries, seednuts are selected from high-yielding mother plants that have other characters believed to be desirable [31, 32]. Because the male parent is unknown, and because the female parent is itself heterozygous, there is no guarantee that the performance of a high-yielding palm will be reproduced in its progeny. Selected palms should therefore be subjected to extensive progeny testing, and subsequently crosses between proved parent trees should be planted. It is obvious that, owing to the long interval between generations, work of this type can be carried out only by research stations with prospects of long continuity. So far, in no country has coconut breeding progressed far enough to give any noteworthy results applicable to large-scale practice.

In Ceylon, Pieris [33] studied in detail various characters of the palm and laid down criteria for a good parent-palm. In 1935 an area of 5 acres was planted with 292 seedlings, the progeny of 9 palms having these characters; this area is now yielding over 12,000 nuts per annum, and in 1949 a comprehensive progeny test was laid down with seedlings therefrom.

Pending the results of such experiments, one can only recommend the use of seednuts from selected high-yielding mother palms with other

(possibly correlated) desirable characters; such nuts having at least a somewhat greater chance of giving superior progeny [34]. In view of their lack of genetical purity, rigorous culling of seedlings in the nursery is also recommended [35]. Other work initiated by Pieris [36] has provided some experimental support for this practice; in 1939 a 6×6 Latin square was laid down to compare six classes: seednuts from high-yielding palms, seednuts from low-yielding palms, and nuts taken from bulked plantation crops; each subdivided into selected and unselected seedlings before transplanting. This experimental area was in good bearing in 1949, and showed a distinct advantage in favour of seedling selection. To facilitate seedling selection, coconuts are preferably put down in nurseries, rather than planted at stake. Field investigations in the Philippines [37], Ceylon [38], and elsewhere have provided a sound basis for nursery management and transplantation, though there is some variation in recommendations made for the latter. Ordinarily in Ceylon, it is recommended that seedlings should be planted out after about 30 weeks in the nursery, when 2 or 3 leaves have developed; at this stage on the average only about 7 roots have developed, of which 4 or 5 have emerged through the husk into the soil.

Germination.—An investigation [39] under the Coconut Research Scheme (Ceylon) showed that there is little difference in weight, whether of total or of dry matter, between a 7-month-old seedling ready for transplantation and the original seednut. Eight hundred nuts were put down in a nursery and 50 taken up for examination every fortnight; each nut was dissected into its component parts, which were weighed; suitable samples were taken for analysis for N (Kjeldahl), K, and moisture. Table 1 summarizes the data relating to the weights of the different parts, omitting the husks and shells.

TABLE 1. *Average Weight (gm.) of Different Parts of the Coconut at Successive Stages of Germination*

Lot no. (50 in each)	*Time in nursery (weeks)*	*Kernel*	*Nut-water*	*Haustorium ('apple')*	*Shoot*	*Leaves*	*Roots*	*Total*
1–4	Up to 6	347·6	133·7	..	..	..	..	481·3
5	8	350·3	145·5	0·2	0·3	..	..	496·2
6	10	352·6	133·0	1·3	0·7	..	..	487·6
7	12	344·0	132·6	3·2	1·4	..	0·6	481·8
8	14	329·4	117·5	12·1	4·3	..	1·9	465·2
9	16	344·3	125·6	25·0	7·9	..	4·1	506·9
10	18	343·9	116·3	44·3	15·0	..	6·6	526·1
11	20	302·9	72·5	72·8	25·3	..	12·0	485·5
12	22	309·7	66·3	89·0	30·2	2·9	15·3	513·4
13	24	300·8	55·3	125·2	33·2	5·8	15·5	535·8
14	26	265·8	16·8	119·3	43·4	12·6	20·6	478·5
15	28	242·4	2·3	120·6	53·1	18·8	24·4	461·6
16	30	215·5	..	132·6	58·5	25·8	27·1	459·5

The carbon compounds in the food reserves of the seed are adequate up to the transplantation stage; the plant is also self-supporting in nitrogen. It had been supposed that ample potash would be available,

owing to the accumulation of this element in the husk, overlooking the rapidity with which potash salts are leached out. Coconut roots do not ramify much in the husk, but mostly go straight through it into the soil; by the time they arrive there (which may be 16 weeks or more after the nut has been put down in the nursery), if much rain has occurred in the interval, residual potash may be inadequate. It was found, in fact, that application of potash fertilizers to nurseries at a convenient stage had a marked effect on seedling-growth.

Manuring

Until recently few systematic manurial experiments on the coconut palm had been carried out, though empirical information of local value was available. Salgado [40] has reviewed earlier work and summarized the results of trials carried out in Ceylon since 1934.

Plot-size.—Joachim [41] and Pieris and Salgado [42], working on different data, agreed that the optimum plot-size, consistent with a minimum standard error, was one of 18 trees, occupying, as ordinarily spaced, about 0·3 acre. In their experiments in Malaya, Belgrave and Lambourne [43] adopted a split-plot design, using 16-tree plots for cultivation treatments and sub-plots of only 4 trees for manurial treatments; this may account for the lack of significant effects due to the latter. Foster [44] in Ceylon fortunately used a 25-tree plot ($\frac{1}{2}$ acre on a widely spaced plantation) for his 4×4 Latin-square experiment.

The principal manurial trials being conducted under the Coconut Research Scheme in Ceylon are: on the main experimental station at Bandirippuwa Estate, Lunuwila, a $3 \times 3 \times 3$ factorial NPK experiment, based on Yates [45], started in 1934. On the sub-station at Ratmalagara Estate, Madampe, a similar experiment on an area newly planted for the purpose in 1948; and a $3 \times 2 \times 2$, K × P × Cultivation (ploughing *v.* no ploughing) experiment laid down in 1943. On co-operating private estates randomized block experiments of a simpler type have been conducted since 1939; on mature palms growing on poor exhausted soils, two trials are in progress, one in the Western and one in the Southern Province; and a manurial trial on young palms underplanted between old palms, the latter being destined for later removal. Salgado [40] has described all these; here only a few salient points are discussed.

Potash has been established as a dominant requirement of the coconut palm. In the Coconut Research Scheme's main experiment, applications of 0·75 lb. K_2O per palm in alternate years gave a significant response in the fifth year (1940) and every subsequent year, and applications of 1·5 lb. K_2O per palm every other year gave a significant response in the third year (1938) and subsequently. Table 2 [46] shows the increments in yield due to these applications calculated as pounds of copra per acre. Even on the comparatively good soil of this experimental area, potash at the higher level has maintained from 1942 to 1947 an average increment of yield of nearly 40 per cent., or over 4 cwt. of copra per acre. Since 1940 the increases of yield have not been linear; from 1942 to 1947 inclusive the $K_1 - K_0$ response has averaged 340 lb. copra per acre, and the $K_2 - K_1$ response 128 lb. Larger applications may therefore

be uneconomic; a third and higher level of potash is being used in the new $3 \times 2 \times 2$ experiment already referred to, which should give further information. Foster [44] also recorded a significant effect due to potash, and Salgado found a potash response on a cover crop experiment to be referred to later.

TABLE 2. *$3 \times 3 \times 3$ NPK Fertilizer Experiment. Coconut Research Scheme, Ceylon* [46]

Fertilizers first applied 1935, November. Increments of Yield due to Potash, calculated as lb. Copra per acre

	Year	K_1–K_0	K_2–K_0		*Year*	K_1–K_0	K_2–K_0
I	1936	26	50	VII	1942	352	470
II	1937	47	80	VIII	1943	300	407
III	1938	47	114*	IX	1944	362	546
IV	1939	28	120*	X	1945	329	422
V	1940	190*	249	XI	1946	312	447
VI	1941	122	196	XII	1947	382	512

* Significant at $P = 0.05$; all subsequent responses significant at $P = 0.01$.
$K_1 = 0.75$ lb., $K_2 = 1.50$ lb., K_2O per palm every alternate (odd) year.

Conversely, palms which had received no potash from 1933, showed by 1940 definite signs of deficiency: yellowing of foliage, and later development of grey blight, a leaf-disease caused by the fungus *Pestalozzia palmarum* Cooke, which especially attacks palms weakened by adverse cultural conditions.

Potash accumulation in husk and nut-water.—The husks and nut-water from plots receiving potash show a content of this element significantly higher than those from plots receiving none. From the possibility of its use as a diagnostic, the nut-water potash has received particular attention. Potassium can be estimated with sufficient accuracy for comparative purposes by direct precipitation as cobaltinitrite from filtered nut-water, and it is thus possible conveniently to handle large numbers of samples.

In the Coconut Research Scheme's factorial experiment, from each of the 54 plots, the water was bulked from 100 nuts (or all if less than 100) and the volume measured; samples were drawn and filtered, and aliquots taken for potash estimations. Calculation gave the amount of K_2O in grammes recovered in the nut-water from each whole plot. Table 3 shows the results for the six crops collected in 1947 [47]. The potash-content of the nut-water increases almost linearly with the doses of potash applied.

Phosphoric oxide.—Neither in Foster's experiment, in which a soluble phosphate was used over 4 years, nor in the Ceylon factorial experiment, where Saphos phosphate has been applied every 2 years from 1935 to 1949, has the slightest response to phosphate been obtained. Both of these trials were on comparatively fertile soils, which had, moreover, for some years prior to the start of the experiments received regular large

applications of phosphatic fertilizers. Salgado [40] gives details of soil analyses illustrating the accumulation of phosphates on these areas.

TABLE 3. *Gross Amount (gm.) of* K_2O *contained in Nut-water of Crop from 18 plots of each Main Treatment of Factorial NPK-experiment* [47]

Date of picking crop	K_0 *No potash*	K_1 *0·75 lb.* K_2O *per palm*	K_2 *1·50 lb.* K_2O *per palm*
7.2.47	207·0	401·7	542·7
8.4.47	348·5	486·5	639·6
19.6.47	330·3	736·6	1006·1
11.8.47	456·0	1003·2	1339·2
10.10.47	248·3	559·4	842·7
10.12.47	268·4	536·0	771·6

On poor lateritic gravels, which contained initially only traces of available (Truog) phosphate, almost spectacular responses were obtained to applications of phosphate equivalent to 0·6 lb. P_2O_5 per palm every 2 years. The long-continuing residual effect of phosphatic fertilizers is noteworthy. Eden [48] found that even 4 years after phosphate applications to Ceylon tea-soils weed-growth (in terms of dry matter) was over 100 per cent. greater than on unmanured plots; Rhind and Tin [49] reported long-sustained residual effects from single dressings of bone-meal, superphosphate, and basic slag on paddy lands in Lower Burma. None of these findings is in accord with prevailing notions of phosphate reversion, particularly in soils high in sesquioxide, and, as Eden suggests, the behaviour of phosphates in tropical soils needs more scrutiny than it has had in the past.

Nitrogen.–In the Ceylon factorial experiment, significant responses to nitrogen were at first obtained, but with the higher dose of 1·0 lb. N per palm did not continue after 1938, nor with the dose of 0·5 lb. N after 1942. It seems likely that under the cultivation régime adopted on the experimental area there is an accumulation of nitrogen in the soil which renders further applications in the form of artificials unnecessary. No cattle-grazing is permitted. The sward, which includes grasses and legumes, is harrowed twice a year and ploughed-in every other year. Calculation from the analysis of pasture samples showed that the biennial ploughing incorporated *inter alia* into the soil 46 lb. of nitrogen and 43 lb. of potash per acre. There is little doubt that excessive amounts of nitrogen depress yields [40].

Minor elements.—There is little information on the coconut palm's requirements of other elements. Application of iron salts has been claimed to increase the yield of palms growing on coral islands [50]. Innes [51] found no evidence that manganese deficiency was a cause of diseases of the leaf and inflorescence; he reported that the limit of adequacy for manganese in coconuts (leaf and inflorescence) was probably not above 10 p.p.m. The coconut fruit has been found to contain little or no boron [52] or zinc [53]. The Coconut Research Scheme

(Ceylon) is studying tapering disease from the point of view of possible mineral deficiencies (*v.s.*).

Other field trials.—Brief reference must suffice to two other field trials carried out by Salgado [40] in Ceylon. From 1937 to 1949 an experiment was carried on at Bandirippuwa Estate on the effect of growing a cover crop (*Centrosema pubescens* Benth.) between coconut palms; it consisted of six randomized blocks of six plots, designed to compare the treatments: no cover+NPK, cover+K, cover+NK, cover+PK, cover+NP, cover+NPK.

The growth of the cover crop produced a sharp decline in coconut yields which reached a maximum in the third year; this was probably connected with a severe drought in 1938. The incorporation into the soil of the cover crop with added fertilizers at the end of 1939 resulted in a recovery in the fourth year of the experiment, which was subsequently maintained. Since then the only significant difference has been the shortfall of yield on plots receiving no potash.

The results of this trial do not suggest that on a short-term basis the growing and control of a specific cover crop give superior results (on lateritic gravel under the conditions of the experiment) to harrowing and ploughing of the natural sward. Extended study is required of cover crops and green manures in the widest sense.

An experiment on growing Napier grass as a subsidiary crop between palms (1939–43) indicated that even with manuring yields of grass were poor. The grass had a depressing effect on coconut yields, corrected by application of nitrogen.

Size of Nut and Oil-content

Coconut oil is and will probably continue to be the principal economic product of the palm. The ultimate criterion of yield should therefore be oil production per acre. In practice it is not possible to process for oil the nuts or copra from a large number of experimental plots, and the presentation of results on the basis of copra yields has to suffice. It is fortunate that a study of oil-contents showed there to be little difference between copra samples from various districts of Ceylon or from palms subjected to different treatments.

Child and Nathanael [54] found 52 samples of Ceylon estate copra to have an average of moisture 6·8, oil (dry basis) 68·3 per cent., and there were no significant differences between samples from the W., NW., E., and S. Provinces. Child and Salgado [55] found that during the second year after application, fertilizer treatments did not affect the contents of oil or nitrogen in the copra. The average oil-content of 96 samples from the Ceylon factorial experiment was 69·3 per cent., and nitrogen 1·04 per cent. (dry weight). Of the 148 samples examined during these two studies, 105 fell in the range 68·1–70·0 per cent. oil-content.

Previously Georgi [56] had found for 62 samples of Malayan copra an average of moisture 6·9, oil (dry basis) 65·6 per cent. Allowing for variations in drying methods, it seems likely that there do exist intrinsic differences in oil-content between nuts from different countries. In the

present state of knowledge, however, it is not possible to relate these to such factors as genetic differences, climate, or soil conditions.

For experimental work in an area of limited geographical and climatic range it is quite adequate to express yields in copra weights. Even the curing of a large number of small lots of copra is tedious, though during the first years of the Ceylon factorial experiment this was actually done six times a year on the separate produce from 972 trees. A further simplification has been possible as a result of the work of Pieris [57], who showed that a very high correlation existed between the weight of husked nuts and the weight of copra therefrom. Pieris recommended that, for purposes of field experimentation, husked nuts from the tree or plot or other unit under investigation be weighed one month after picking; 32 per cent. of this weight gives, to a sufficient approximation, the amount of copra the nuts would yield. In Ceylon this regression coefficient has been adopted with satisfactory results, although as Child [58] has pointed out it is less accurate outside the normal range of nut-size. Similarly (in Ceylon) 20 per cent. of the husked-nut weight gives a reasonable estimate of the weight of oil therefrom.

Whilst manuring has not been found significantly to affect oil-content, it is otherwise with nut-size, or more precisely with the weight of kernel, and so of copra per nut. Salgado [40] showed that potash tends to increase kernel weight, and nitrogen to diminish it. On poor soils a complete NPK mixture improved kernel weight by as much as 10 per cent.; on the non-factorial experiments it was not possible to disentangle the individual effects of nitrogen, potash, or phosphoric acid.

Reference has already been made to the influence of manuring on female-flower formation and the percentage setting of nuts.

Coconut products.—The scope of the present article has been confined to agricultural research. In producing countries there has also been much work directed to the improvement of coconut products. The importance of the coconut palm as a factor both in the external and the internal economy of these countries has been increasingly realized. In 1939 the Commonwealth of the Philippines set up by legislation [59] a 'National Coconut Corporation' with an initial capital of 2 million pesos for the purpose of 'adjusting the coconut industry to a position independent of trade preferences in the United States'. The war interrupted the Corporation's work, but since 1946 the Philippine coconut industry has shown good recovery. In 1944 the Government of India set up a Central Coconut Committee [60], well financed and with extensive powers, including firstly 'undertaking, assisting or encouraging agricultural, industrial, technological and economic research' on the coconut palm and its products.

Most recently, in 1949, a strong Commission in Ceylon has published a 123-page report with sweeping recommendations for fostering the island's coconut industry in all its branches, with largely increased provision for research [61]. In its report the Commission discusses the industry in its general relation to world supplies of oils and fats.

The average yield of just over a million acres of coconut land in Ceylon is roughly 5–6 cwt. in terms of oil per acre, and the average in other

countries cannot be much higher than this. Annual yields equivalent to ½ ton of oil are readily obtainable on ordinary well-cared-for lands, and yields of ¾ t. are not unknown. The above discussion on manuring referred to increments of yield obtained by suitable use of fertilizers of the order of 4 cwt. of copra (or, say, 3 cwt. of oil) per acre, and the Ceylon Coconut Commission (*Rept.*, ch. xvi) lays great stress on manuring and recommends a subsidy on fertilizers. It is possible to envisage in Ceylon alone an overall increase in annual output equivalent to 1 or 2 cwt. of oil per acre, or a total of at least 50,000 t. of oil, by the extension of manuring and good cultivation.

By the application in all coconut-producing countries of present technical information, it is certain that the world's fat supplies could be increased by 250,000 t. annually at a fraction of the cost of clearing land for the same production from annual crops. As Sir John Russell said in his Presidential Address to the British Association, 1949: 'Most countries could increase their food production considerably by applying known methods of improvement and raising the average performance to the level of the best' [62].

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REFERENCES

1. Leo Schnurmacher Inc., Review of Coconut Products for 1938. Manila, Commonwealth of Philippines, 1939.
2. T. P. Hilditch, World Fat-supplies in relation to the Needs of Great Britain and the Commonwealth. The Advancement of Science, 1949, **5**, No. 20, 322–8.
3. E. B. Copeland, The Coconut. Macmillan & Co., 3rd edition 1931 (previous editions 1914 and 1921).
4. H. C. Sampson, The Coconut Palm. John Bale, Sons & Danielsson Ltd., 1923.
5. J. S. Patel, The Coconut: a Monograph. Govt. Press, Madras, 1938.
6. P. Lepesme, Les Insectes des Palmiers. Paris, 1947, pp. 113–14.
7. O. Beccari, Philippine J. Sci., 1917, **12** C, 27–43.
8. E. Werth, Verbreitung, Urheimat und Kultur der Kokospalme. Ber. Deutsch. Bot. Ges., 1933, **51**, 301–14.
9. B. A. Baptist, The Control of Insect Pests of Coconut. Paper read before the Coconut Conference, Colombo, Ceylon, 4 July 1947, 38–44.
10. T. H. C. Taylor, The Campaign against *Aspidiotus destructor* Sign. in Fiji. Bull. Entom. Res., 1935, **26**, 1–102.
11. J. D. Tothill, T. H. C. Taylor, and R. W. Paine, The Coconut Moth in Fiji. Imp. Bur. of Entomology, 1930.
12. Y. Ramachandra Rao *et alii*, Control of the Coconut Caterpillar by its Parasites. Agric. J. India, 1926, **21**, 452–9; Yearbook, Dept. Agric., Madras, 1926, 39–51; 1927, 11–12.
13. K. P. Antananayaran, On the Bionomics of a Eulophid *Trichospilus pupivora* Ferr., a Natural Enemy of the Coconut Caterpillar *Nephantis serinopa* Meyr. in South India. Bull. Entom. Res., 1934, **25**, 55–61.
14. T. J. Jayaratnam, A Study of the Control of the Coconut Caterpillar in Ceylon with reference to its Eulophid Parasite *T. pupivora* Ferr. Trop. Agriculturist (Ceylon), 1941, **96**, 3–21.
15. H. R. Briton-Jones, The Diseases of the Coconut Palm. Baillière, Tindall & Cox, 1940.
16. E. J. Butler, Some Diseases of Palms. Agric. J. India, 1906, **1**, Pt. 4.

17. M. Park and M. Fernando, Diseases of Village Crops in Ceylon. Govt. Press, Colombo, 1941.
18. A. Sharples, Rept. Imp. Bot. Conf., London, 1924, 147–53; also, Lightning Storms and their Significance in relation to Diseases of *Cocos nucifera*. Ann. Appl. Biol., 1933, **20**, 1–22.
19. R. A. Altson, Malayan Agric. J., 1941, **29**, 249–50.
20. C. H. Gadd, Ann. Rept. Tea Res. Inst., Ceylon, Bull. 8, 1931, 18; Bull. 26, 1944, 25–8; Tea Quarterly, 1936, **9**, 6.
21. Rept. Dept. Agric., Ceylon, 1920, 13–15. M. L. M. Salgado, Coconut Research Scheme, Ceylon, 1938. Bull. No. 3, 33–4.
22. Private information.
23. C. H. Gadd. Nut-fall of Coconuts. Dept. Agric. Ceylon, 1922, Bull. No. 53.
24. Coconut Research Scheme, Ceylon, Ann. Rept., 1944, 11.
25. —— —— Ann. Rept., 1947, 11.
26. Trop. Agriculturist, 1941, **96**, 253–4.
27. J. K. Santos, Philippine J. Sci., 1928, **37**, 417.
28. E. J. Janaki-Ammal in C. D. Darlington and E. K. Janaki-Ammal, Chromosome Atlas of Cultivated Plants, 1945, p. 317.
29. H. W. Jack and W. N. Sands, The Dwarf Coconut in Malaya. Malayan Agric. J., 1922, **10**, 4–13; Observations on the Dwarf Coconut in Malaya, ibid., 1929, **17**, 140–70.
30. Coconut Research Scheme, Ceylon, Ann. Rept., 1947, p. 8.
31. N. B. Mendiola, A Manual of Plant-breeding for the Tropics, Manila, 1926, Chapter 9. Coconut Breeding.
32. H. Hunter and H. M. Leake, Recent Advances in Agricultural Plant-breeding, 1933, 326–31.
33. W. V. D. Pieris, Studies on the Coconut Palm I. Morphological Characters and Standards of Selection. Trop. Agriculturist, 1934, **82**, 75–97.
34. Coconut Research Scheme, Ceylon, Leaflet No. 1. Seed Selection.
35. —— —— Leaflet No. 2. Nursery Management and Selection of Seedlings; and No. 14, Further Notes on Seedling Selection.
36. Coconut Research Scheme, Ann. Rept., 1947, p. 8.
37. R. B. Espino, On the Germination of Coconuts. Philippine Agric., 1923, **11**, 191–200.
38. W. V. D. Pieris, Coconut Research Scheme (Ceylon), Ann. Rept., 1935, p. 5.
39. R. Child and W. V. D. Pieris, Unpublished observations.
40. M. L. M. Salgado. Recent Studies of the Manuring of Coconuts in Ceylon. Paper read before Section B of the Ceylon Association of Science, 1945; Trop. Agriculturist (Ceylon), 1946, **102**, 149–54; 206–18; 1947, **103**, 5–11; reprinted as Coconut Research Scheme (Ceylon), 1948, Bull. No. 6.
41. A. W. R. Joachim, A Uniformity Trial with Coconuts. Trop. Agriculturist, 1935, **85**, 198–207.
42. W. V. D. Pieris and M. L. M. Salgado, Experimental Error in Field Experiments with Coconuts, ibid., 1937, **89**, 75–85.
43. W. N. C. Belgrave and J. Lambourne, Malayan Agric. J., 1933, **21**, 206–11. W. N. C. Belgrave, ibid., 1932, **20**, 105; 1934, **22**, 511–38; 1937, **25**, 179–86.
44. H. E. Foster, Manurial Experiment on Coconuts. Trop. Agriculturist, 1937, **89**, 63–7.
45. F. Yates, The Design and Analysis of Factorial Experiments. Imp. Bur. of Soil Sci., 1937, Tech. Comm. No. 35.
46. Coconut Research Scheme, Ann. Rept., 1947, p. 10.
47. —— —— p. 13.
48. T. Eden, Tea Research Institute (Ceylon), 1947, Bull. No. **29**, p. 26; 1948, Bull. No. **30**, p. 39.
49. D. Rhind and U. Tin, Trop. Agriculturist (Ceylon), 1948, **104**, 12.
50. Bolin, Bull. Mat. Grasses, 1929, 183.
51. R. F. Innes, The Manganese-content of Leaf and Inflorescence Tissue in relation to the 'Unknown Disease' of the Coconut Palm in Jamaica. Trop. Agriculture (Trinidad), 1949, **26**, 57–60.

52. A. S. DODD, The Natural Occurrence of Boron Compounds in Fruits and Vegetable Products, Analyst, 1929, **54,** 15.
53. G. BERTRAND and B. BENZON, Bull. Soc. Hyg. Aliment., 1928, **16,** 457.
54. R. CHILD and W. R. N. NATHANAEL, Ceylon Estate Copra. Trop. Agriculturist, 1937, **88,** 137–49; 1943, **99,** 203–6.
55. —— and M. L. M. SALGADO, The Effect of Manuring Coconut Palms on the Oil- and Protein-contents of the Copra, ibid., 1941, **97,** 4–9.
56. C. D. V. GEORGI, The Oil-content of Malayan Estate Copra. Malayan Agric. J., 1929, **17,** 335–40.
57. W. V. D. PIERIS, Studies on the Coconut Palm, II. On the Relation between the Weight of Husked Nuts and the Weight of Copra. Trop. Agriculturist, 1935, **85,** 208–20.
58. R. CHILD, Coconut Shells as an Industrial Raw Material, III. Estimated World Production. Current Science, 1944, **13,** 150–2.
59. Commonwealth Act No. 518, approved May 7, 1940.
60 Indian Coconut Committee Act, 1944. Gazette of India, 1944, Pt. V, p. 9.
61. Rept. of the Coconut Commission, 1949. Ceylon Govt. Sessional Paper XII, 1949.
62. E. J. RUSSELL, World Population and World Food Supplies. The Advancement of Science, 1949, **6,** 173–83.

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CONFOUNDING IN SPLIT-PLOT DESIGNS WITH RESTRICTED RANDOMIZATION OF SUB-PLOT TREATMENTS

MUKHTAR SINGH

(*Agronomist, Central Tobacco Research Institute, Rajamundry, Madras Province, India*)

Introduction.—THANKS to the development of field experimental technique, the experimenter to-day is much more fortunately placed than his predecessors to tackle the problems of crop production, which invariably involve a multiplicity of factors. One of the most interesting and useful recent developments in factorial experimentation is split-plot confounding. There are many attractive arrangements in this system of field-plot layout, and these have been broadly dealt with by Yates [1]. In one of the types, on the analogy of reduction in block-size, the main-plot size is reduced by confounding, with the main plots, the interaction between sub-plot factors. Thus the 'confounded' interaction is subject to the same errors of estimation as the other main-plot factors under study, and the sub-plot comparisons gain in accuracy. Examples of designs of this type and useful modifications have been given by Finney [2] and Kempthorne [3] with methods of analysis.

Yates's plaid square and half-plaid square constitute another set of useful designs which are analogous to the quasi-Latin squares, with the difference that the mean responses of some of the factors are also confounded with the whole rows or columns of the square for reasons of agricultural convenience. This involves some loss of information on the treatments assigned to whole rows or columns. The latter difficulty can, however, be overcome at least in part by modifying the design to some extent. It is not obligatory that the numbers of longitudinal and transverse divisions should be equal—a condition implicit in squares. The only condition is that the levels of the main-plot and sub-plot treatments should be such as to yield a convenient system of confounding. The picture presents itself in relatively simple form in experiments where all factors have the same number of levels, and it is there that split-plot confounding is likely to find most use. Simple cases of such designs in 2×2 and 4×4 systems were tried in 1940 by Dastur *et al.* [4]. Modified designs of this type in 3×3 systems were employed in a 'study of the factors influencing the development and the yield of the potato' at the Edinburgh and East of Scotland College Farm, Boghall, in 1946 and 1947 [5]. It is proposed to publish elsewhere the results of the investigation from the agronomic and physiological standpoint. A brief description of the layout and statistical aspects of the designs will be considered here to illustrate the usefulness of the split-plot-cum-confounded designs. Before coming to these actual examples, it is, however, necessary to describe in general the methods of constructing such designs and the structure of their analysis.

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Construction of Confounded Split-plot Experiments and the Structure of their Analysis

The procedure in designing such experiments is similar to that for the half-plaid squares. The treatment combinations are first split into sets, the contrast of which is equivalent to the interactions to be confounded. These sets are written in parallel rows or columns. The treatments are then shifted within the sets to create grouping, in the other direction, corresponding to main-plot-treatment combinations containing all levels of the sub-plot factor or factors. Finally, *the sets as well as the main plots are reshuffled within each replicate or block.*

An example of an experiment with 3 factors (A, B, C) at 2 levels, in which combinations of A and B are meant to be main-plot treatments and $A.B.C$ is confounded with the complementary sub-blocks of *one* replicate, is given below to illustrate the steps in designing:

(i) Generation into sets. $A.B.C$ confounded

$a_0b_0c_0$	$a_1b_0c_0$
$a_1b_1c_0$	$a_0b_1c_0$
$a_1b_0c_1$	$a_0b_0c_1$
$a_0b_1c_1$	$a_1b_1c_1$

(ii) Treatments rearranged within sets to create main plots for A and B factors

a_0b_0	c_0	c_1
a_1b_1	c_0	c_1
a_1b_0	c_1	c_0
a_0b_1	c_1	c_0

(iii) Randomizing between sets and between main plots

a_0b_0	c_1	c_0
a_1b_0	c_0	c_1
a_1b_1	c_1	c_0
a_0b_1	c_0	c_1

The partition of the 31 d.f. in the analysis of variance with four replicates of such an experiment will take the form:

Due to	*d.f.*	*Due to*	*d.f.*	*Due to*	*d.f.*
Replicates	3	(Replicates	3)		
A, B, $A.B$	3	$A.B.C$	1		
Error (1)	9	Replicates × $A.B.C$	3		
Main plots	15	Sub-blocks within replicates	4	(Main plots and blocks	19)
				C, $A.C$, $B.C$	3
				Error (2)	9
				Total sub-plots	31

Evidently the second error is freed of two-way systematic soil variation, between main plots in one direction and between sub-blocks in the other.

Similarly, a 2^4 or 4×2^2 experiment can be arranged with 8 main plots (per replicate), each main plot split in 2, confounding 1 d.f. across.

A 2^5 experiment may be laid out with 8 combinations of 3 of the factors as main-plot treatments, and 4 combinations of the remaining 2 factors as sub-plot treatments, confounding 3 d.f. among the complementary sub-blocks of a replicate.

The following scheme has C, D, E as main-plot factors and A, B as sub-plot factors and confounds $A.B.C$, $A.D.E$, $B.C.D.E$. This could be used after randomization in 2 or more replicates.

Sub-plot Treatments

c d e	*ab*	*ab*	*ab*	*ab*
0 0 0	00	10	01	11
1 0 0	01	11	00	10
0 1 0	11	01	10	00
0 0 1	11	01	10	00
1 1 0	10	00	11	01
1 0 1	10	00	11	01
0 1 1	00	10	01	11
1 1 1	01	11	00	10

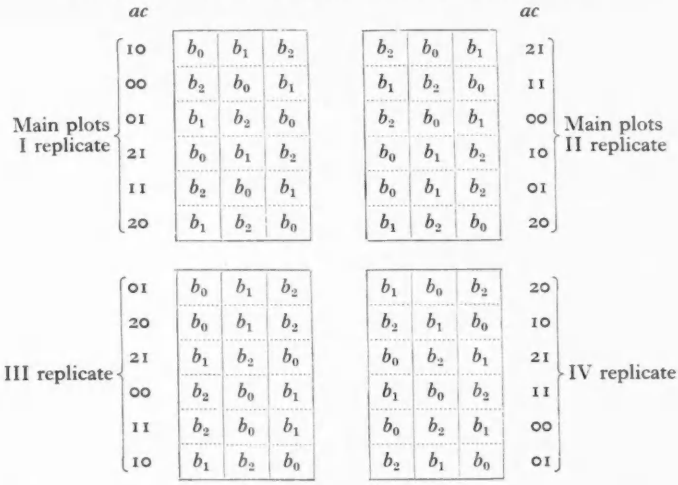
Alternatively, different sets of interactions can be confounded in different replicates, provided none of the sets selected for confounding contains an interaction (e.g. $C.D.E$ in the above example) which is studied from the main-plot part of the analysis.

With $3\times3\times3$ experiments confounded sets have been tabulated by Yates [1]. The arrangement is such that confounded split-plot arrangement can readily be had by choosing one or more of the groups designated as W, X, Y, Z and then randomizing sets (1, 2, 3) as well as main plots comprising combinations of the first and the second factors. More complicated cases of 3^n types can also be designed without much difficulty by an extension of the same principle. This will become clear when reference is made to actual examples discussed in the next section.

The designs are equally applicable to cases where some factors are at 2 and the others at 3 levels. An example of the $3\times3\times2$ design (duly randomized) in 4 replicates is given below, with the 6 combinations of the first and the third factor as main-plot treatments split for the 3 levels of the second factor, confounding the second and first order interactions partially.

Quality-cum-quantity experiments involving the presence of dummy treatments frequently complicate the statistical analysis if confounding, alone or with split-plot arrangement, is resorted to and should be designed carefully. A case of $3\times3\times3$ experiment with 3 levels of nitrogen (n_0, n_1, n_2) in 3 forms (q_1, q_2, q_3) in combination with 3 levels of organic manure (m_0, m_1, m_2) may be considered. It is certainly convenient in a case like this to introduce another higher level (n_3) of the quantity factor so as to give a $4\times3\times3$ experiment wherein only the $3\times3\times3$ system, viz. $\begin{pmatrix} n_1 & q_1 & m_0 \\ n_2 & q_2 & m_1 \\ n_3 & q_3 & m_2 \end{pmatrix}$ takes part in the confounding scheme, which splits the treatments into groups of 9, whereas each sub-block

3×3×2 Design with Split Plots and Confounding



actually consists of 12 plots, i.e. includes 3 additional plots for the 3 levels of organic manure at 0 level of N.

The main effect of Q and its interactions may simply be studied according to the conventional meanings usual to factorial experiments in general, rather than the specialized meanings [6, 1] envisaged by the hypothesis that qualitative effects are proportional to the quantities.

Furthermore, the 12 combinations of the levels of N with those of organic manure may be assigned to the main plots, split transversely for the forms of N so that treatments belonging to the confounded sets lie across, intermingled with the additional treatments n_0m_0, n_0m_1, n_0m_2. The sub-plot comparisons can then be freed from the transverse soil heterogeneity.

The degrees of freedom in the analysis of an experiment of this type with two replicates, confounding $Q.N.M$ (2 d.f.), will partition as below:

Due to	*d.f.*	*Due to*	*d.f.*
Replicates	1	Sub-blocks (within replicates)	4
		Q	2
N	3	$Q.N$	4
M	2	$Q.M$	4
$N.M$	6	$Q.N.M$ (unconfounded)	6
		$Q.N.M$* (confounded)	2
Error (1)	11	Error (2)	26
Main plots	23	Sub-plots (within main plots)	48

* Confounded component freed from sub-block differences by adjustment with sub-block evaluations of $n_0(m_0+m_1+m_2)$.[1]

[1] It is possible that in the absence of confounding this component may be usefully employed to correct the treatment effects influenced by transverse soil variation.

It may be added that if a $3 \times 3 \times 3$ experiment containing quality treatments is laid out in 9-plot blocks resorting to usual confounding, with or without split-plot arrangement, in 2 or 4 replicates, the block variation within the replicates may still be eliminated as if it were a $2 \times 3 \times 3$ experiment in 6-plot blocks containing additional treatments. As happens in confounded experiments with unequal levels of different factors, there will be some loss of information also on the lower-order interaction.

ACTUAL EXAMPLES

$3^3 \times 2$ *Experiment with Potatoes, 1946*

Site.—Two acres were selected for this experiment in the Anchordales field at the Boghall experimental farm. The soil was more or less uniform in texture and level in one direction (N.–S.), but it became more and more sandy and had a distinct regular downward slope from the west to the east as far as the middle of the area selected, followed by a more or less uniform and level ground.

Treatments and layout.—The experimental treatments were all combinations of 3 planting-dates, 3 spacings, 3 seed-sizes, and 2 times of lifting. The experimental area was divided up into 4 main blocks (replicates), $121\frac{1}{2}$ ft. $\times$ 150 ft. to lie in 2 rows. Three unplanted headlands, 20 ft. wide each, were provided for the movement of implements from plot to plot. The 9 combinations of planting-time and spacing lay in a random order in long narrow main plots $13\frac{1}{2}$ ft. $\times$ 150 ft. running the entire block length in each of the 4 main blocks. Each main plot was split across into 3 plots, $13\frac{1}{2}$ ft. $\times$ 50 ft. for the allocation of the 3 seed-sizes at random, with the restriction that the 3-factor interaction was confounded with the transverse sub-blocks thus formed within the main blocks. There were 8 degrees of freedom, forming 4 orthogonal pairs, corresponding to the second-order interactions and different pairs were confounded in different blocks, attaining a perfect balance in the 4 replicates. Before lifting, the 12 sub-blocks were split transversely for the 2 times of lifting. The layout plan with yields is given in Table 1.

The salient features of the layout are: (1) Large, long, and narrow main plots for the planting dates facilitated agricultural operations and reduced the area under headlands. (2) Six rows per plot at 27 in. constant drill-width permitted the use of two-row and three-row implements without any waste of labour. (3) Long and narrow main plots and almost square blocks were provided as potential devices to keep down experimental error. (4) The seed-size treatments lay end on, by transverse division of the main plots. Any risk of fertility gradient, as suggested by the slope, influencing the sub-plot comparisons, was covered by confounding. (5) The drills ran E.–W. to minimize shading of neighbouring plots, as plants with different ages were growing side by side in long narrow plots.

Statistical analysis.—The mean squares for the different components in the analysis of variance of the yield data on the sub-plot basis are given in Table 2.

The analysis of the main-plot section is simple enough. Attention should be paid to two points, in particular, for the semi-main-plot

TABLE 1. *Layout Plan of the $3^3 \times 2$ Experiment (1946)*

Block No.	X_2		X_3		X_1		Z_2		Z_1		Z_3		
	t_2	t_1	t_2	t_1	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2	
d_1 8″	*m* 648	701	*l* 655	647	*s* 528	606	*s* 583	647	*l* 724	735	*m* 612	555	d_1 16″
d_2 8″	*s* 708	561	*m* 620	585	*l* 643	631	*l* 562	537	*m* 502	568	*s* 446	482	d_3 8″
d_2 24″	*l* 623	414	*s* 465	459	*m* 442	475	*m* 702	760	*s* 644	729	*l* 748	601	d_1 8″
d_3 24″	*m* 538	435	*l* 511	520	*s* 424	383	*l* 614	653	*m* 573	598	*s* 494	517	d_2 16″
d_1 16″	*l* 715	688	*s* 711	576	*m* 438	475	*s* 541	621	*l* 622	637	*m* 613	537	d_2 8″
d_3 8″	*l* 551	507	*s* 519	450	*m* 518	487	*m* 523	454	*s* 421	442	*l* 528	457	d_3 16″
d_1 24″	*s* 520	453	*m* 547	518	*l* 348	425	*m* 503	557	*s* 513	538	*l* 544	488	d_2 24″
d_2 16″	*s* 492	385	*m* 494	437	*l* 491	476	*l* 641	681	*m* 595	660	*s* 579	527	d_1 24″
d_2 16″	*m* 645	516	*l* 654	598	*s* 518	532	*s* 437	478	*l* 508	476	*m* 484	434	d_3 24″
d_1 24″	*s* 559	578	*l* 628	551	*m* 437	478	*l* 592	633	*s* 541	517	*m* 603	526	d_2 24″
d_1 16″	*l* 645	725	*m* 630	627	*s* 562	567	*m* 448	411	*l* 514	494	*s* 416	347	d_3 16″
d_1 8″	*m* 688	673	*s* 647	658	*l* 718	693	*s* 624	536	*m* 572	580	*l* 727	569	d_2 16″
d_3 24″	*m* 600	549	*s* 505	594	*l* 622	626	*s* 670	654	*m* 693	658	*l* 750	657	d_1 8″
d_2 8″	*l* 636	625	*m* 632	664	*s* 530	543	*l* 677	620	*s* 646	601	*m* 615	553	d_1 16″
d_3 24″	*l* 509	569	*m* 449	547	*s* 391	442	*s* 429	424	*m* 491	459	*l* 519	444	d_3 24″
d_2 16″	*s* 512	572	*l* 613	629	*m* 583	651	*m* 666	535	*l* 687	658	*s* 589	526	d_2 8″
d_3 16″	*m* 548	591	*s* 409	479	*l* 592	577	*m* 709	635	*l* 682	630	*s* 632	524	d_1 24″
d_3 8″	*s* 497	507	*l* 577	627	*m* 551	540	*l* 602	522	*s* 496	482	*m* 572	455	d_3 8″
	t_1	t_2	t_1	t_2	t_1	t_2	t_2	t_1	t_2	t_1	t_2	t_1	
Block No.	Y_3		Y_1		Y_2		W_1		W_3		W_2		

← 150 ft. → ⟨13½⟩

d_1, d_2, d_3 denote successive planting dates. } Main-plot treatments.
8″, 16″, 24″ denote interset spacing in inches. }
s, *m*, *l* denote small, medium, and large seed: semi-main plot treatment.
t_1, t_2 denote early and the late lifting: array strip treatment.
W, *X*, *Y*, *Z* denote four blocks of three sub-blocks (1, 2, 3) each [cf. Yates, 1].
Yields in ¼ lb. per sub-plot (1/220 acre).

TABLE 2. *Analysis of Variance (1946 Experiment) Sub-plot Basis*

Due to	*d.f.*	*m.sq.*	*Due to*	*d.f.*	*m.sq.*	*Due to*	*d.f.*	*m.sq.*
Blocks	3	18,612	Sub-blocks	8	11,450			
D	2	313,911*	*Ss*	2	82,088*	*T.D*	2	982
Sp	2	106,151*	*D.Ss*	4	3,192	*T.Sp*	2	501
D.Sp	4	7,312	*Sp.Ss*	4	4,305	*T.Ss*	2	2,865
			D.Sp.Ss	8	1,694	*T.D.Sp*; *T.D.Ss*; *T.Sp.Ss*	12	814
Error (*a*)	24	6,276	Error (*b*)	46	2,003	Error (*d*)	78	1,085
Main plots	35		Semi-main plots	107		Sub-plots	215	
			T	1	58,115*			
			Error (*c*)	11	5,876			
			Strips (within sub-blocks)	12				

* Significant at 1 per cent. level.

D, *Sp*, *Ss*, and *T* denote planting-date, spacing, seed-size, and time of lifting factors, respectively.

For brevity, further components of treatment effects are not given in the table.

N.B. Early planting, close spacing, large seed-size, delayed lifting, increased the yield individually and their effects were largely additive.

section. (1) There are 8 d.f. for sub-blocks within replicates and the sum of squares corresponding to these should be computed by difference (Total sub-block *S.S.*—replicate *S.S.*) and accounted for here. (2) The sum of squares for each pair of degrees of freedom for the three-factor interaction should be derived from the appropriate three replicates, in which a particular pair of d.f. is not confounded. As only three-quarters of the plots take part in these calculations, the correction terms and the divisors will be different.

The computational work for the first two sections can be carried out most simply by analysing the experiment as a $3 \times 3 \times 3$ confounded experiment following the usual steps [1, pp. 43–5], but inserting the calculated sum of squares of the different components at the appropriate places in the analysis, the structure of which is drawn up in advance on the basis of the restrictions imposed in the form of split-plot arrangement or confounding.

For the array-strip section the 'local control' has 11 d.f., 3 of which have already been accounted for, as replicates, in the main-plot section and 8, as sub-blocks within replicates, in the semi-main-plot section. The sum of squares calculated from the direct differences between the strip pairs (12 d.f.) minus the main effect *S.S.* for lifting-time (1 d.f.) gives the third estimate of error.

Having accounted for 107 d.f. as semi-main plots and 12 d.f. as strips (within sub-blocks), the fourth section of the analysis follows the usual procedure in sub-plot analysis, basing error on 78 d.f.

Although *T.D.Sp.Ss* is partially confounded with the strips, as a consequence of the array-strip arrangement for lifting time, within sub-blocks, the four-factor interaction can reasonably be ignored and consigned to error in the analysis pertaining to strips (within sub-blocks) as well as the sub-plots (within strips and semi-main plots) as shown in Table 2.

Efficiency of design.—The transverse sub-blocks created by confounding removed considerable variation. The gain in efficiency can be computed by the method of Yates [1]. Error (*b*) mean square would have risen from 2,003 to 3,052, in the absence of confounding (Table 3).

TABLE 3. *The Effect of Transverse Restrictions (through Confounding and Array-strip Arrangement) on the Error Estimates*

	m.sq. (sub-plot basis)		*Error ratios*		*S.E. per plot (direct basis)*				
					(1) *As designed*		(2) *No transverse restrictions*	*Plot sizes*	
	(1) *As designed*	(2) *No transverse restrictions*	(1) *As designed*	(2) *No transverse restrictions*	*tons p.a.*	*% mean*	*% mean*	*ft.×ft.*	*acre*
(*a*) Error main plot	6,276	6,276	5·78	3·88	0·794	5·75	5·75	9×132	1/36·6
(*b*) Error semi-main plot	2,003	3,052	1·85	1·89	0·777	5·63	6·94	9×44	1/110
(*d*) Error sub-plot	1,085	1,617	1	1	0·809	5·86	7·15	9×22	1/220
(*c*) Error arrays	5,876	..	1	..	0·621	4·49	..	81×22	1/24·4
Sub-blocks	11,450	..	1·95	..	..	..	..	..	..

Similarly, in the absence of an array-strip arrangement for lifting time, the error (*d*) mean square would have risen from 1,085 to 1,617. Thus the three errors would have been in the ratio of 1:2:4, roughly in a straightforward successive plot division, unconfounded and without array-strip arrangement. The transverse restrictions altered the ratio to 1:1·85:5·78 approximating closely to the corresponding sub-plots in the semi-main plots and the main plots, i.e. 1:2:6. Similarly, the ratio of the variance for the lifting-time strips to the sub-blocks was 1:1·9. In other words, standard errors per plot were maintained over a considerable range of plot sizes. The errors per plot were unusually low. A plot as small as 1/220 acre gave less than 6 per cent. S.E. per plot. Although, normally, standard errors per plot increase as the plot-size is reduced below 1/20 or 1/40 acre, the effectiveness of confounding contributed to the accuracy of even much smaller plots, through efficient local control.

$3^4 \times 2$ *Experiment on Potatoes, 1947*

Site.—As in 1946, the area selected for the 1947 experiment was not a level piece of ground. The area selected had a very high centre and sloped downward regularly to the east as well as the west. Correspondingly, the low-lying places had comparatively heavy texture and the high ground was more sandy. The field was more or less even in the other direction, though it tended to be lighter S.–N.

Treatments and layout.—The area was divided into 4 equal divisions. One division was set apart for growth observations on selected treatments and 3 for laying out a 5-factor experiment in single replication. Nitrogen (3 levels) and potash (2 levels) were introduced as new factors

in addition to planting-date, spacing, and seed-size of the previous season.

The 3 divisions, referred to above, furnished 3 blocks of 9 main plots each for the $3 \times 3 \times 3$ formation of the three cultural factors (planting-date, spacing, and seed-size), thus confounding the 2 degrees of freedom with the fertility differences of the 3 blocks. Each main plot (measuring $13\frac{1}{2}$ ft. $\times$ 164 ft.) was split across for 3 levels of nitrogen. The distribution of the 3 levels of nitrogen to the plots was random, with the restriction that some of the second-order interactions of *N* with the main-plot treatments were confounded with the transverse sub-blocks formed within main blocks. Each of the 81 *N*-plots was sub-divided transversely for the allocation of 2 potash levels, strictly at random. The sub-plot at planting measured $13\frac{1}{2}$ ft. $\times$ 24 ft., and 4 ft. buffer strips ran across the transverse divisions in each main block to prevent the movement of manures with implements. Table 4 gives the layout plan of the experiment, together with the yields.

Statistical analysis.—The analysis of variance of the main-plot part of the experiment, which also involves confounding, follows essentially the standard procedure outlined by Yates [1, pp. 53–5] whereby the main effect and the first-order interactions (linear $\times$ linear) can be compared with a pooled estimate of the remaining components (15 d.f.) after eliminating the main-block variations (*Ss.D.Sp* (*Z*), 2 d.f.). For the semi-main plot part of the analysis, the main effects of *N* and its interactions with *D*, *Sp*, and *Ss* can be calculated from two-way tables in the usual manner. Moreover, it is necessary to realize that the restriction imposed on the complete randomization of *N* to the semi-main plots is allowed for in the analysis. The variation between the sub-blocks within main blocks is, therefore, to be eliminated from the estimate of the second error, which may be assessed only from the remaining second- and third-order interactions. The third error is simply calculated by deducting the sum of squares corresponding to potash and its first-order interactions from that of the total within plot (81 d.f.) sum of squares.

Efficiency of the design.—It is at once apparent that the yields were more variable than in the preceding year. This may be partly ascribed to the variable site, and partly to season (1947 was exceptionally dry in summer). Still the errors were, in general, of the order encountered in well-conducted experiments. The gain through confounding was particularly high (Table 6).

The ratios of variances of the successively larger plots to that for the sub-plot (sub-plot basis of analysis) would have been 1 : 2·56 : 5·72 in case no confounding were adopted. With confounding, the error (*b*) was reduced as low as sub-plot error (*c*). Thus the ratio error (*a*)/error (*b*) = 5·7, whilst the corresponding semi-main plots per main plot were 3. The mean square for the sub-plot error (*c*) would have also gone down considerably if a transverse restriction could be imposed.

A reduced estimate of the sub-plot error comparable to error (*d*) of the 1946 experiment could, however, be obtained as follows, ignoring sub-plot-treatment effects other than those of *N* and *NK*.

TABLE 4. $3^4 \times 2$ *Experiment on Potatoes (1947). Yield in* $\frac{1}{4}$ *lb. per sub-plot* $= 1/242$ *acre*

Sub-block No.	*Main block II* 7		6		2		*Main block I* 9		1		5		
$s.d_2$ 12″	n_2k 378	n_2 340	n_1k 454	n_1 430	.. 275	k 269	.. 206	k 263	n_1k 362	n_1 473	n_2k 488	n_2 480	$l.d_1$ 12″
$m.d_1$ 12″	k 190	.. 212	n_2 419	n_2k 583	n_1k 487	n_1 364	n_1k 311	n_1 386	n_2 398	n_2k 459	k 337	.. 292	$l.d_2$ 8″
$s.d_1$ 16″	n_1 328	n_1k 380	k 282	.. 296	n_2k 533	n_2 399	.. 230	k 255	n_1k 312	n_1 393	n_2 407	n_2k 441	$m.d_3$ 8″
$m.d_3$ 16″	n_2 369	n_2k 446	n_1 391	n_1k 452	.. 337	k 355	n_1 436	n_1k 466	n_2 431	n_2k 474	.. 455	k 384	$m.d_1$ 16″
$l.d_2$ 16″	.. 196	k 261	n_2k 455	n_2 353	n_1k 390	n_1 388	n_1k 355	n_1 333	n_2k 393	n_2 415	k 294	.. 280	$s.d_3$ 12″
$m.d_2$ 8″	n_1k 345	n_1 279	.. 311	k 447	n_2k 525	n_2 445	n_2 458	n_2k 516	k 334	.. 318	n_1 504	n_1k 529	$s.d_1$ 8″
$l.d_1$ 8″	n_2 426	n_2k 495	n_1 496	n_1k 583	.. 462	k 450	n_2k 503	n_2 441	k 322	.. 318	n_1k 534	n_1 485	$m.d_2$ 12″
$l.d_3$ 12″	n_1 287	n_1k 350	k 317	.. 308	n_2 366	n_2k 448	k 373	.. 296	n_1 456	n_1k 512	n_2 492	n_2k 521	$s.d_2$ 16″
$s.d_3$ 8″	k 215	.. 184	n_2 314	n_2k 396	n_1k 402	n_1 330	n_2 391	n_2k 509	k 374	.. 331	n_1k 420	n_1 425	$l.d_3$ 16″
							n_2 362	n_2k 571	k 350	.. 255	n_1 425	n_1k 469	$s.d_2$ 8″
							n_1k 428	n_1 422	n_2k 439	n_2 416	k 356	.. 274	$l.d_3$ 8″
							k 268	.. 249	n_1 342	n_1k 393	n_2 413	n_2k 403	$s.d_3$ 16″
							.. 309	k 406	n_1 443	n_1k 459	n_2k 543	n_2 505	$m.d_1$ 8″
							n_1 325	n_1k 454	n_2 408	n_2k 470	k 328	.. 300	$m.d_2$ 16″
							n_2k 478	n_2 400	k 380	.. 346	n_1 458	n_1k 554	$l.d_1$ 16″
							k 295	.. 325	n_1 379	n_1k 438	n_2 366	n_2k 473	$l.d_2$ 12″
							n_2 372	n_2k 453	k 381	.. 309	n_1k 435	n_1 419	$m.d_3$ 12″
							n_1k 436	n_1 326	n_2k 528	n_2 401	.. 271	k 211	$s.d_1$ 12″

Sub-block No. 3 4 8 — *Main block III*

s, m, l	denote	small, medium, and large seed.
d_1, d_2, d_3	,,	successive planting-dates.
8″, 12″, 16″	,,	spacings in inches.
n_1 and n_2	,,	S/A at $2\frac{1}{2}$, 5 cwt. per acre.
k	,,	muriate of potash at 2 cwt. per acre.

If seed-size (*Ss*), planting-date (*D*), nitrogen (*N*), and spacing (*Sp*) are numbered as the 1st, 2nd, 3rd, and 4th factors respectively, then *Ss.D.Sp* [*Z*] is confounded with main blocks and *Ss.N.Sp* [*W*], *D.N.Sp* [*Y*], and *Ss.D.N* [*X*] are confounded with sub-blocks, in Yates's notation.

TABLE 5. *Analysis of Variance. Final Yield (1947 Experiment) (Sub-plot Basis)*

Due to	*d.f.*	*m.sq.*	*Due to*	*d.f.*	*m.sq.*	*Due to*	*d.f.*	*m.sq.*
Blocks	2	9,492	N'	1	488,840†	K	1	83,277†
D'	1	73,581†	N''	1	57,493†	$N.K$	2	7,250†
Ss'	1	7,600	$Q'.N'$	1	6,962*	$D.K$	2	1,363
Sp'	1	77	$Sp'.N'$	1	539	$Sp.K$	2	475
D''	1	16	$Ss'.N'$	1	7,729*	$Ss.K$	2	380
Ss''	1	8,983	$D'.N''$	1	2,716			
Sp''	1	15,805	$D''.N'$	1	6	Remainder = error (c)	72	1,423
$D'.Ss'$	1	242	$Sp'.N''$	1	296			
$D'.Sp'$	1	27,612	$Sp''.N'$	1	5,985*	Sub-plots	161	
$Sp'.Ss'$	1	1,467	$Ss'.N''$	1	1,014			
Remainder = error (a)	15	8,141	$Ss''.N'$	1	54			
			$D''.N''$	1	11			
Main plots	26		$Sp''.N''$	1	1,823			
Sub-blocks (within blocks)	6	21,065	$Ss''.N''$	1	4,428			
			Remainder = error (b)	34	1,466			
			Plots	80				

* Significant at 5 per cent. level.

† Significant at 1 per cent. Single dash = linear component; double dash = quadratic component.

N.B. Early planting, nitrogen, and K individually influenced yield. Response to N was enhanced in the presence of potash and declined with the delay in planting. Small seed as well as medium spacing (12 in.) were more conducive to treatment with nitrogen.

TABLE 6. *The Effect of Transverse Restrictions (through Confounding) on the Error Estimates*

	m.sq. (sub-plot basis)		*Error ratios*		*S.E. per plot (direct basis)*			*Plot sizes*	
					(1) *As designed*		(2) *No transverse restrictions*		
	(1) *As designed*	(2) *No transverse restrictions*	(1) *As designed*	(2) *No transverse restrictions*	*tons p.a.*	*% mean*	*% mean*	*ft.* × *ft.*	*Acre*
(*a*) Error main plot	8,141	8,141	5·72	5·72	0·995	9·48	9·48	9 × 120	1/40·3
(*b*) Error semi-main plot	1,466	3,644	1·03	2·56	0·731	6·96	11·0	9 × 40	1/121
(*c*) Error sub-plot	1,423	1,423	1	1	1·019	9·70	9·70	9 × 20	1/242

1. A table of the expected sub-plot yields which would have been obtained in the absence of any K or NK effects is first prepared, from the semi-main-plot totals and the three effects of K at 0, 1, and 2 levels of N, which are 27·85, 36·55, and 71·63 quarter-lb. per sub-plot respectively, e.g. the expected yields of n_2k_1 and n_2 sub-plots under Sd_2 12″ (Table 4) are:

$$\frac{(378+340)+71{\cdot}63}{2} = 394{\cdot}81 \text{ and } \frac{(378+340)-71{\cdot}63}{2} = 323{\cdot}19$$

respectively.

2. The deviation of the expected yield from the actual yield is then worked out for each of the 162 sub-plots in turn. As a consequence the effects of K and NK, as well as of semi-main plots, are simultaneously eliminated, inasmuch as a sum of squares computed from these deviations corresponds to 78 d.f. and checks with that obtained by difference.

3. The deviations are totalled across to calculate sum of squares due to 9 d.f. strips (within sub-blocks). A 69 d.f. sum of squares for error is residual to the strips after eliminating K and NK. Table 7 summarizes the results of the calculation.

TABLE 7. *Calculation of Error for the Sub-plot Comparisons, 1947 Experiment*

Due to	*d.f.*	*S.S.*	*m.sq.*	*Remarks*
K and NK . . .	3	97,778	..	Elimination of strips reduced the S.E. per plot to 0·92 tons p.a. or 8·8% of general mean.
Strips (within sub-blocks) .	9	25,687	2,854	
Error	69	81,231	1,177	

Returning to Table 5, the comparison of the mean square for error (*a*), appropriate to the main-plot comparisons with that for the sub-blocks, indicates that the direction of the run of the main plots within the main blocks was sound. The variability N.–S. was much smaller in magnitude than that of E.–W. The error corresponding to the main plots would have been inflated if the position of the main plots were shifted through a right angle. Besides, this change would have placed the sub-plots at no advantageous position, for the gain through confounding would have been meagre. This emphasizes the importance of preliminary inspection of the field and a knowledge of slope, fertility gradient based on the growth of previous crops, as guides in the choice of design and its actual layout in the field.

Summary

The paper gives a general account of the construction of 'split-plot with confounding' designs and describes two such experiments laid out at the College of Agriculture Farm, Boghall, Edinburgh, in 1946 and 1947. In these designs the use of long and narrow main plots, running full block-length in a single row within each main block, acted as compensating device for the accuracy of the main-plot comparisons and was consistent with practical ease in the conduct of agricultural operations. The sub-plots lay across with the narrow ends touching and the precision of the sub-plot comparisons was assured by 'confounding' the higher-order interactions with the transverse sub-blocks within replicates. The designs adopted were essentially a modification of Yates's half-plaid square adapted to cases where transverse divisions were not necessarily equal to the longitudinal divisions (a condition implicit in squares).

The efficiency of the designs was worked out and gave encouraging results.

These designs have a strong claim to attention as they combine workability with increased efficiency on worthwhile comparisons, without drawing heavily on the accuracy of the main-plot comparisons. Wherever the use of split plots is imperative, the possibility of introducing 'confounding' with the split-plot design should, as a rule, be examined.

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REFERENCES

1. F. YATES, The Design and Analysis of Factorial Experiments. Imp. Bur. Soil Sci. Tech., 1937, Comm. No. 35.
2. D. J. FINNEY, Recent Developments in the Design of Field Experiments. I. Split-plot Confounding, J. Agric. Soc., 1946, **36**, 56–62. II. Unbalanced Split-plot Confounding, ibid., 63–8.
3. O. KEMPTHORNE, Recent Developments in the Design of Field Experiments. J. Agric. Sci., 1947, **37**, 156–162.
4. R. H. DASTUR, MUKHTAR SINGH, and SUCHA SINGH, Further Experiments on the Amelioration of Tirak. Ind. J. Agric. Sci., 1944, **14**, 152–60.
5. MUKHTAR SINGH, A Study of the Factors influencing the Development and the Yield of the Potato. Ph.D. Thesis, 1948. Edinburgh University.
6. R. A. FISHER, The Design of Experiments, 1st ed., 1935. Oliver & Boyd Ltd., Edinburgh.

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PASTURE PRODUCTIVITY IN MID-WALES

PART I. EXPERIMENTAL METHODS OF MEASUREMENT

R. O. DAVIES,[1] W. E. J. MILTON,[2] AND J. R. LLOYD[3]

WITH PLATE 9

Introduction.—FOR several years the need has been widely felt for quantitative information regarding the yield of nutrients produced by different types of pastures in Britain. Such knowledge is necessary in relation both to general agricultural policy and to the farm programme in various districts and on individual farms. The very restricted information so far available on this subject is largely due to the formidable difficulties encountered in evaluating the productivity of pastures. These difficulties arise from the fact that there are several possible ways of measuring their productivity, all of which are open to criticism and none of which can be applied with equal success to all sets of circumstances. A further factor adding greatly to the difficulty is that the productivity of grassland is a highly variable quantity dependent not only on soil, season, and climatic conditions, but also on the management of the sward and grazing animal.

Therefore any experimental work on pasture productivity should in the first instance concern itself principally with a critical comparison of the methods that might be employed for its estimation; and such critical comparisons are now in active progress in several countries. A review of the literature on the methods of estimating the yield of herbage is given by Linehan and Lowe [1], and methods of evaluating pastures including the cage method have been discussed by Ahlgren [2]. The present article deals with the experience obtained over three seasons in comparing different methods of measuring pasture productivity at a centre four miles east of Aberystwyth. The project involved the co-ordination of several activities directed towards gaining quantitative knowledge regarding the productivity of lowland pastures. It included much agronomic work and necessitated a detailed control of the grazing animal and its periodic veterinary inspection and treatment against pests and possible minor-element deficiency. It also included the sampling, preparation, and chemical analysis of 1,820 grass samples, and the botanical examination of an equal number. Both the chemical data from the grass cuts and the live-weight data were subjected annually to statistical analysis by the Rothamsted Experimental Station, whose guidance was also obtained on the choice of a sampling method best suited to statistical treatment.

Two of the methods used for a quantitative measure of herbage-growth involved cutting techniques in which grass was cut at regular intervals, the grass being weighed and analysed botanically and chemically. The third method involved the grazing of the sward by sheep and lambs, which were weighed immediately before and after the grazing periods. These methods were carried out conjointly on three different kinds of pasture: (*a*) old permanent pasture which for many years had

[1] University College, Aberystwyth. [2] Welsh Plant Breeding Station.
[3] National Agricultural Advisory Service.

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not received limestone or fertilizer, (*b*) old permanent pasture that had received limestone and fertilizers, and (*c*) old permanent pasture ploughed and reseeded after receiving the same quantity of limestone and fertilizers. The experiment was arranged so as to provide suitable plots for rotational grazing and a randomized replication of each kind of pasture.

Lay-out of experiment.—The experiment was laid out on a gently sloping field at an altitude of 110 ft. The soil on the shoulder of the field was of the Penrhyn series and consisted of a light to medium loam 11 in. deep on a stony subsoil, the rock being within 25 in. of the surface. In the depression the soil was a medium loam of the Sarnan series having a depth of 10 in. and lying on a medium loam containing very few stones. At a depth of 24 in. there was a deep stratum of medium to heavy material of finer texture.

The whole field, being a very old permanent pasture, was well supplied with humus to a depth of 10–11 in., and contained an adequate supply of available potash. It showed a deficiency in lime and phosphate. Apart from a small area on the Sarnan series, which became waterlogged in winter, the experimental field was well drained and there was a tendency to suffer from drought during dry periods in the spring and summer. Owing to exposure to the easterly winds spring growth generally started somewhat late.

No manures had been applied to the field within living memory and there was no recollection of its ever being ploughed. It had been used for mixed grazing by dairy cattle, sheep, and horses, and was of a definitely higher standard of productivity than the average permanent pastures of the district. A botanical analysis of the sward carried out before the experiment began in April 1945 showed it to consist of

	Per cent.		*Per cent.*
Perennial rye-grass (*Lolium perenne* Linn.)	8½	Bent (Agrostis species)	40½
Cocksfoot (*Dactylis glomerata* Linn.)	1½	Sweet vernal (*Anthoxanthum odoratum* Linn.)	6½
Crested dogstail (*Cynosurus cristatus* Linn.)	9¼	Yorkshire fog (*Holcus lanatus* Linn.)	5¾
Rough stalked meadow grass (*Poa pratensis* Linn.)	12½	Wild white clover (*Trifolium repens* Linn.)	11¼
Red fescue (*Festuca rubra* Linn.)	2¼	Miscellaneous weeds	2¼

Total number of tillers per 6-in. mesh was 450.

The lay-out of the experimental plots is shown in Fig. 1, each plot being of ¼ acre, and a general view of the plots is shown in Plate 9A. There were 12 plots in all, and they were separated by a strong fencing of posts and pig-netting. Each plot was provided with a field gate so as to facilitate surface cultivations, manuring, and the movement of animals. Four of the randomized plots (1, 1A, 1B, 1C) consisted of unmanured permanent pasture. Two plots (2, 2A) contained limed and fertilized permanent pasture, and another two (3, 3A) were ploughed, limed, cultivated, fertilized, and reseeded. In plots 4, 4A the centre portion, making one-quarter of the total plot area, was left in permanent pasture to which limestone, but no fertilizers, was applied. The remainder of these plots was reseeded after receiving identical treatment to plots 3, 3A. In plots

5, 5A the centre portion, again making up a quarter of the total area, received the same reseeding treatment as plots 3, 3A. The bulk (three-quarters) of the area of plots 5, 5A was left in permanent pasture, which was limed and fertilized as in plots 2, 2A. Thus the experimental plots can be grouped as follows:

1. Control plots consisting of permanent pasture receiving no limestone or fertilizers (plots 1, 1A, 1B, 1C).

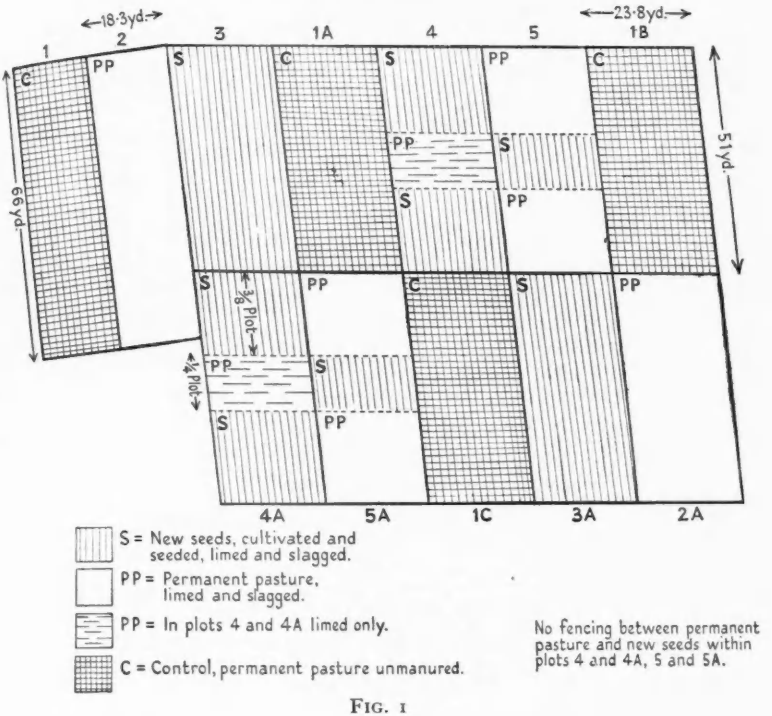


FIG. 1

2. Permanent pasture plots to which limestone and fertilizers were applied (plots 2, 2A).
3. Reseeded plots receiving the same limestone and fertilizers as the permanent pasture plots (plots 3, 3A).
4. Mainly reseeded plots but containing 25 per cent. of the area under permanent pasture (plots 4, 4A).
5. Mainly permanent pasture plots but having 25 per cent. of the area reseeded (plots 5, 5A).

Where limestone and fertilizers were applied they were given at the same rate to all the areas. Limestone was applied to the centre portions

of the permanent pasture in 4, 4A, but manures were intentionally withheld from these small areas with the object of finding whether the limestone alone would encourage the development of miscellaneous herbs, as had occurred in a grazing experiment on the uplands of Cardiganshire [3].

The plots to be reseeded were ploughed on March 1, 1945, ground limestone at the rate of 34 cwt. per acre being applied a week after ploughing together with 10 cwt. per acre of basic slag (12% P_2O_5). The cultivations were completed by April 19, when 1 cwt. per acre of nitro-chalk was applied and the following seeds-mixture sown (lb. per acre):

Italian rye-grass (*Lolium italicum* Braun.)	8		
Perennial rye-grass: commercial .	4	blend of three Aberystwyth strains	14
Cocksfoot: commercial . . .	2	blend of two Aberystwyth strains	4
White clover: S. 100 (Aberystwyth strain)	1	Kentish	1
Total per acre	34 lb.		

Methods of measuring productivity.—Two cutting techniques were used for assessing the productivity of the plots. The first, Technique 1, was based on the measurement of the rate of growth of grass trimmed with shears to $\frac{3}{4}$ in. from ground-level; the second, Technique 2, was based on the difference between the yield from caged but untrimmed areas and the yield from an adjacent grazed area when the cages were set down. The cages used were steel frames covered with 1 in. wire netting at the sides and $3\frac{1}{2}$ in. netting over the top. An area of 4×4 ft. was enclosed by the cage; and the cut taken from the site within each cage consisted of 1 sq. yd. With both techniques the site was protected during the grazing period by these small movable cages (Plate 9*b*). The sites for the cages in the different plots were decided by means of a system of randomization, and the cages were moved to a new randomly chosen site at intervals of 3 weeks. The grass cuttings were weighed and immediately dried at 80° C., the dry matter being chemically analysed. The following illustrates the use of the two techniques in determining the yield of dry matter.

Technique 1. A cage was set on a random site on May 29, 1945, after 1 sq. yd. had been trimmed to within $\frac{3}{4}$ in. of ground-level. Growth from May 29 to June 18 was obtained by cutting on June 18 to within $\frac{3}{4}$ in. of ground-level. Weight of dry matter obtained, representing growth for period, 88·0 gm.

Technique 2. A cage was set similarly on May 29, 1945, but the area inside the cage was left untrimmed. On May 29 1 sq. yd. was cut to $\frac{3}{4}$ in. of ground-level outside the cage and adjacent to it on a predetermined and fixed side of the cage. Weight of dry matter: 177·8 gm. A cut of 1 sq. yd. was taken within the cage on June 18, and gave 270·1 gm. dry matter. Hence growth for period was $270{\cdot}1 - 177{\cdot}8 = 92{\cdot}3$ gm.

Both techniques were replicated twice on each plot.

Besides these cutting techniques the productivity of the plots was also measured by weighing the sheep and lambs grazing them. On the evening of the day before grazing the animals were weighed and again before any further grazing on the following morning, the animals having been fasted over night; the mean of the two figures was taken as the weight. A similar procedure for the weighing of the animals was adopted at the end of the grazing period. The desirability of taking records of sheep-weights after an overnight fast was demonstrated by Jones [4].

To arrive at an estimate of the amount of grass consumed by the sheep some random cuts were taken at the start and end of grazing. Two separate estimates of the growth in the intervening period were obtained in accordance with the above two cutting techniques.

The silica was determined in all the grass samples, and where it exceeded 2 per cent. it was attributed to the contamination of the grass with soil. The dry-matter figure was corrected for soil contamination and a corresponding correction was made in the other chemical constituents.

The basic data provided by the experiment consisted therefore, on the one hand, of the yield and chemical composition of the dry matter obtained during the season by means of the two cutting techniques, and, on the other, the live-weights of the grazing animals.

Results

The first grazing season.—As the reseeded plots were cultivated and seeded in the spring of 1945, the grazing of the permanent-pasture plots began earlier than that of the reseeded plots. The selection of the sheep and lambs for these different plots was made at random from the flock available at the farm, but where there was an obvious discrepancy in the average weight of the sheep or the lambs in any lot, an adjustment was made to bring the average to the same level in the different lots.

It was evident from the very start that the grazing of the experimental plots would be a matter of personal judgement, and that both the welfare of the stock and the pasture had to be considered. During the seeding year of the ley it was felt that the primary consideration was the establishment of the grass, and rotation of the stock from one plot to the other was arranged with this main object in view. During subsequent seasons the main object was the welfare of the stock, and the management was arranged so as to provide the most favourable conditions for the development of the lambs; the management of the pasture was always kept in view as a secondary but most important consideration.

Through the co-operation of the Veterinary Investigation Officer the experimental sheep were dosed once a month with phenothiazine tablets against worm infestation, the dosing of the lambs commencing when they were 3 months old. The herbage was also at intervals examined for worm infestation and at no period was the count abnormally high. The importance of eliminating worm infestation as a disturbing factor in animal productivity experiments on pastures has been emphasized by Roberts and Williams [5]. All the grazing animals were also dosed with mineral-supplement tablets supplying iron, copper, cobalt, iodine, and

manganese. This co-operation with the Veterinary Officer was of the greatest importance, as the main object of the experiment was to measure the energy and protein supplied for animal maintenance and production by the herbage. To attain this aim it was obviously imperative to eliminate disturbances caused through disease or through the absence of certain minor but essential elements.

The rate of stocking for each pair of ¼-acre plots had to be decided at the outset of grazing the permanent pasture in May, and this decision had to be made in the light of the grazing available on the different plots. On May 15, when grazing began, the limed and fertilized permanent-pasture plots contained more keep than the control plots. Following the inspection of these plots, the selected grazing animals for each pair of control plots comprised six couples, whilst seven couples were allocated to the pair of manured plots. This allocation was in reasonable proportion to the amount of keep available, as may be seen from the average weight of dry matter on the control plots and the manured plots on the day when grazing commenced. The protein-content of this dry matter indicates the similarity in composition between the produce of the control and manured plots.

	Control plots	*Manured plots*
Mean yield of dry matter per sq. yd. . . .	128 gm.	155 gm.
Protein, per cent.	16·6	16·9

Quarter sections of plots 4, 4A, i.e. the sections that contained permanent pasture, were grazed with one couple (a ewe and a lamb) whilst three-quarter sections of plots 5, 5A, i.e. the permanent-pasture sections, were grazed with four couples. The former plots gave a mean yield of 124 gm. dry matter per sq. yd., as compared with 159 gm. per sq. yd. from the latter. The stocking of these plots therefore also showed a close connexion with the keep available, as subsequently determined from the dry-matter yields. The rotation of the sheep from plot to plot was determined by the amount and nature of keep available. Throughout the grazing period the sheep were supplied with an adequate amount of fresh water in troughs.

The grazing of the seeded areas began on June 3. The seeded sections in plots 4, 4A and plots 5, 5A were, until this date, protected with temporary fences from the sheep and lambs that were already grazing the permanent-pasture areas in those plots. The average weight of dry matter on the reseeded areas amounted to 98 gm. per sq. yd. at this time, and accordingly 6 couples were introduced into plots 3 and 3A, 5 couples into plots 4 and 4A, and 4 couples into plots 5 and 5A. A reduction had to be made in the number of couples on the permanent-pasture plots, both control and manured, to correspond with the diminution in growth. The initial growth from the reseeded areas in 3, 3A, 4, 4A was so rapid that the sheep and lambs were unable to cope with it, and therefore a temporary flock of sheep had to be used as followers in order to keep the sward under control. For this purpose a flock of 30 sheep was needed for 5 days to eat down the surplus growth in plots 3, 3A, and a flock of 24 sheep for 5 days to consume the surplus growth in plots 4, 4A.

Allowance has been made for these sheep in the subsequent estimations of starch equivalent produced by these plots. During the period Sept. 4 to Oct. 2 the experimental plots were grazed with lambs only, and 5 to 6 lambs were allocated to each pair of plots according to the amount of grass available.

During this first season some trouble was experienced on account of maggots and foot-rot. The foot-rot trouble was somewhat more severe on the seeded areas than on the permanent pasture. It was realized that in 1945 the facilities for controlling these ailments were inadequate, and that treatment in good time with DDT and the provision of foot-baths for copper-sulphate treatment were essential requirements for the following season.

During this first and subsequent seasons the grazing behaviour of the sheep was largely dependent on the nature of the sward. It was found that the reseeded grass was more uniformly and closely grazed than the permanent grass, whether manured or unmanured. Where the area of the plots was made up of 75 per cent. permanent grass and 25 per cent. seeds (5, 5A) the sheep always grazed the reseeded area first. Where the area was made up of 25 per cent. permanent grass and 75 per cent. seeds there seemed to be no definite choice, but it was noticeable that the permanent grass was more closely grazed on these plots than on other plots that offered a higher proportion of it to the sheep.

The three seasons combined.—In Table 1 the yield of dry matter and the concentration of crude protein from the different groups of plots is given for the three experimental seasons.

TABLE 1. *Grass Productivity by Cutting Techniques for Seasons 1945–7*

	Technique 1		*Technique 2*	
Season	*Dry matter gm./sq. yd.*	*Crude protein %*	*Dry matter gm./sq. yd.*	*Crude protein %*
Group 1. Control (plots 1, 1A, 1B, 1C)				
1945	437	18·6	493	15·6
1946	247	18·3	281	16·0
1947	406	17·0	406	15·7
Mean	363	18·0	393	15·8
Group 2. Manured pasture mainly permanent (plots 2, 2A, 5, 5A)				
1945	495	20·0	535	17·6
1946	254	18·1	350	15·9
1947	456	17·1	599	15·5
Mean	402	18·4	495	16·3
Group 3. Manured pasture mainly reseeded (plots 3, 3A, 4, 4A)				
1945	432	25·3	472	22·8
1946	227	17·6	310	15·2
1947	355	17·1	441	15·0
Mean	338	20·0	408	17·7

It will be recalled that in the first year the reseeded areas did not contain sufficient grass for grazing until June 3, but enough grass for grazing

was present on the permanent pasture by May 15. In spite of this late start on the reseeded areas, the yield of dry matter from the 'seeds' in 1945 according to Techniques 1 and 2 was very similar to that obtained from the unmanured permanent pasture. It can therefore be said that the loss of time entailed during the early part of the seeding year in ploughing and reseeding had been fully recovered by the more rapid growth made by the reseeded grass compared with the old grass; and also the new growth was definitely higher in crude protein than the old grass.

The grazing of the experimental plots in 1946 was also carried out by sheep and lambs, the Welsh Mountain ewes having been crossed with a Ryland ram, whereas in 1945 a Kerry ram had been used. Also for the 1946 season's work a foot-rot bath was erected for the better control of that complaint, and in addition the sheep were treated with DDT against maggot fly. As in the previous year the sheep and lambs were dosed with phenothiazine and a mixture of trace elements. The lambs were also treated against pulpy kidney disease.

In 1946 grazing began on the permanent pasture and on the reseeded plots on April 24 and was continued until July 31. The data indicate that according to Technique 1 the differences are not very marked in the yield of dry matter derived from the groups of pastures. According to Technique 2, although there is no appreciable difference between the mean yield from the control plots and the reseeded areas, a considerably higher yield is obtained from the manured permanent grass. The concentration of protein is of the same order in the three groups, and whereas in comparison with 1945 the protein has been maintained at the same level as in the previous season in the permanent pasture, there has been a marked deterioration in the protein of the reseeded areas.

No live-weight data were obtained from the plots after the removal of the sheep and lambs at the end of July. For the remainder of the season the plots were grazed with cattle, and a record made of grass production by means of the cutting techniques.

In April 1947 North African phosphate (25 per cent. P_2O_5) at 2 cwt. per acre was applied to all the plots previously manured, and on July 24 nitro-chalk at the same rate was given to the whole experimental area, including the control plots. The nitro-chalk was given during a short interval when all the plots were being rested owing to dry, hot weather causing an absence of growth over the whole experiment. Its application immediately preceding rain greatly helped in providing fresh growth. Yearling wether lambs were used for the 1947 grazing season as suitable couples were not available owing to the disastrous effect of the winter snow on the hill flocks (Plate 9*c*).

The data in Table 1 indicate a slight diminution in protein-content of all groups of pastures compared with the previous season. Whereas Technique 1 shows a greater yield from the manured permanent pasture, it also indicates a lower yield from the manured and reseeded pasture. Technique 2 shows a greater difference than Technique 1 between the unmanured and manured permanent pastures. In Technique 2 the reseeded pasture gave a greater yield than the unmanured permanent pasture.

It is seen from Table 1 that Technique 2 generally gave higher results for the yield of dry matter than Technique 1. The material from Technique 1 consisted of younger growth than that obtained under Technique 2 and, as expected, it contained a higher percentage of crude protein. According to both techniques the mean yields of dry matter obtained from the manured permanent-pasture plots over the three seasons is higher than that from the unmanured plots, whilst the mean yields from the reseeded plots are similar to those from the control plots. In Table 2 the live-weight increase and the grazing days obtained from the different groups of pasture plots are shown.

TABLE 2. *Live-weight Increase and Grazing Days obtained from Experimental Plots during Seasons 1945–7 (Totals in each instance for 1 acre)*

Season	*Live-weight increase (lb.)*			*Grazing days*		*Total equivalent sheep-days*
	Sheep	*Lambs*	*Total*	*Sheep*	*Lambs*	
Group 1. Control (plots 1, 1A, 1B, 1C)						
1945	17½	194¼	211¾	653	933	1,119
1946	53	219	272	788	634	1,105
1947*	249	..	..	1,353	..	..
Group 2. Manured pasture mainly permanent (plots 2, 2A, 5, 5A)						
1945	−34½	+240½	206	645	925	1,108
1946	59½	251	310½	856	634	1,174
1947	281	..	..	1,692	..	..
Group 3. Manured pasture mainly reseeded (plots 3, 3A, 4, 4A)						
1945	4½	198¼	202¾	740	844	1,182
1946	69½	281	350½	834	733	1,201
1947	293	..	..	1,681	..	..

* Wethers were used in 1947 instead of ewes and lambs.

In 1945 there was hardly any difference in the mean total live-weight increase obtained from the three different groups of plots. This is partly due to the late date at which grazing could be started on the reseeded plots when the rate of growth in lambs had diminished, whereas on the permanent-pasture plots the lambs were grazing when at the maximum rate of growth. However, a very satisfactory relative live-weight increase was forthcoming from the reseeded plots. It has already been mentioned that an additional flock had to be introduced for a short period into the reseeded plots to control the initial rapid growth, which accounts for the greater number of sheep-grazing-days from these plots as compared with the permanent-pasture plots.

The data for 1946 illustrate the fact that there is no necessary relationship between the total grass grown in an area (Table 1) and the live-weight data resulting from the grass actually consumed. Thus whilst Table 2 shows a higher live-weight increase from the reseeded plots than from the permanent pasture, Table 1 shows a lower productivity from the reseeded plots. One reason for this difference is the more complete consumption of the reseeded grass than of the permanent grass by the

sheep. This is clearly indicated from the quantities of ungrazed herbage left behind by the sheep at the end of the grazing period for this second year.

Uneaten Herbage at end of Grazing (gm. per sq. yd.)

Control		*Manured permanent pasture*		*Manured reseeded pasture*	
1, 1A . .	89	2, 2A . .	100	3, 3A . .	34
1B, 1C . .	82	5, 5A . .	87	4, 4A . .	42
Mean . .	86		94		38

The reseeded herbage actually consumed during the season amounted to 83 per cent. as compared with 65 and 61 per cent. for the unmanured and manured permanent pasture respectively. The following figures give the actual amount of dry matter (in gm. per sq. yd.) consumed according to the two techniques:

	Permanent pasture (unmanured)	*Permanent pasture (manured)*	*Reseeded pasture (manured)*
Technique 1 .	161	155	189
Technique 2 .	195	251	272

The amount of dry matter consumed is, according to both techniques, greater in the reseeded pasture than in the permanent pasture.

During the grazing period of 1947 the wethers available were adequate at the commencement to deal with the growth in the plots. When, however, the late spring growth eventually started it became so rapid that the sheep were unable to cope with it. This was especially the case with the grasses that produced flowering heads which largely remained uneaten. Consequently, a cut had to be taken with a grass mower from all the plots at the end of June. These cuts were weighed and analysed and a correction made on their account in the grazing data given in Table 3 (p. 214).

In addition, during their period of flush growth a flock consisting of 7–9 couples was introduced into every plot for 2–3 days to eliminate the surplus growth. These 'flying' flocks have been taken into account in reckoning the grazing days given in Table 2, and also in calculating the starch equivalent obtained from grazing shown in Table 3 for this third season.

Table 2 shows that a somewhat higher live-weight increase was obtained in 1947 from the manured permanent pasture and from the manured reseeded plots than from the control plots. The number of grazing-days derived from the manured plots, both permanent pasture and reseeded, are considerably higher than those grazed from the control plots.

The figures in Table 1 indicate the total growth on the plots during the season, but the growth consumed by the sheep has been arrived at by subtracting the growth left behind after grazing in each plot. To

compare the consumption data obtained from the grass cuts with the live-weight increase, both sets of data have been converted to starch equivalents. The starch equivalents consumed by the grazing animals have been estimated from their maintenance requirements and increase in live-weight in accordance with the following table. The yields of dry matter in the experiments were converted to starch equivalents by the following regression equation, which is based on analyses given by Woodman [6] and Watson [7]:

Starch equivalent $\rightarrow 60{\cdot}8 + 1{\cdot}34\ (P - 16{\cdot}5)$, where P is the percentage of crude protein.

Starch Equivalent Table for Sheep[1]

Sheep weight in lb.	*Starch equivalent for maintenance*		*Sheep weight in lb.*	*Starch equivalent per 1 lb. live-weight increase*
	per week	*per day*		
–22	3·0	0·43	37–9	1·2
23–7	3·5	0·50	40–3	1·25
28–33	4·0	0·57	44–7	1·3
34–9	4·5	0·64	48–53	1·35
40–5	5·0	0·71	54–60	1·4
46–52	5·5	0·79	61–9	1·45
53–9	6·0	0·86	70–8	1·5
60–6	6·5	0·93	79–87	1·6
67–73	7·0	1·00	88–92	1·7
74–80	7·5	1·07	93–6	1·8
81–8	8·0	1·14	97–100	1·9
89–96	8·5	1·21	101–4	2·0
97–105	9·0	1·29	105–7	2·1
106–15	9·5	1·36	108–11	2·2
116–25	10·0	1·43	112–14	2·3
126–35	10·5	1·50	115–18	2·4

Neither the live-weight nor the dry-matter conversions can be regarded as entirely satisfactory, but they are the best available methods for converting the data to a common basis pending the development of a more satisfactory means.

The production of starch equivalent from the different groups of plots over the three experimental seasons as shown by the two cutting techniques and by the weight of sheep and lambs is given in Table 3.

With regard to the sheep-grazing figures no standard error can be satisfactorily obtained since variation in the consumption of one animal is certain to produce variation in the consumption of the others. Under these conditions the theory associated with the calculation of standard error is no longer applicable.

[1] The requirements given in this table for sheep of 60 lb. and over are based on the usual English feeding standards [6]. The requirements for sheep under 60 lb. weight are estimates only, as no determinations of needs are available for such animals. No claim is made that these figures represent the actual needs of Welsh sheep of different live-weights, and their use is restricted to throwing light on the relative progress of similar groups of sheep whose initial weight is of the same order.

TABLE 3. *Grass Productivity expressed as Starch Equivalents (cwt. per acre) from the Experimental Plots by the Cutting Techniques and by Sheep-grazing (Seasons 1945–7)*

Sheep-grazing		*Grass-cutting*		*Grazing yield as % of grass-cutting*	
Season		*Technique 1*	*Technique 2*	*Technique 1*	*Technique 2*
Group 1. Control (plots 1, 1A, 1B, 1C)					
1945	14·8	17·6	23·8	84·0	62·5
1946	12·5	10·8	11·8	117·0	113·0
1947	12·0	13·9	12·0	88·0	101·0
Mean	13·1	14·1	15·9	96·3	92·2
Group 2. Manured pasture mainly permanent (plots 2, 2A, 5, 5A)					
1945	14·6	19·4	22·8	70·0	66·0
1946	13·6	11·8	15·8	116·0	86·0
1947	14·0	14·7	21·8	92·0	65·0
Mean	14·1	15·3	20·1	92·7	72·3
Group 3. Manured pasture mainly reseeded (plots 3, 3A, 4, 4A)					
1945	13·9	21·9	22·4	63·5	62·5
1946	15·2	11·6	15·5	132·0	99·0
1947	14·4	13·3	16·3	113·0	89·0
Mean	14·5	15·6	18·1	102·8	83·5

	Technique 1			*Technique 2*		
	1945	*1946*	*1947*	*1945*	*1946*	*1947*
Standard error per plot	±2·4	±1·1	±1·6	±4·6	±1·2	±2·5

The high standard errors of the two cutting techniques in the first year were to be expected because it was in this season that the plots were cultivated and sown. There was a large variation in the initial density of cover provided by the seeds, and, as indicated, the control of the first flush of new grass necessitated the temporary introduction of a flying flock. The percentage utilization of the grass consumed amounts to an average of 72·5 when consumption is measured according to Technique 1, and only to 63·7 when the grass consumed is measured by Technique 2. In the light of the subsequent data it is considered that this low consumption is partly due to factors that interfered with the well-being of the animals during this initial season. When factors other than nutritional cause a disturbance to the grazing animal, the animal under such circumstances cannot be expected to reflect the true productivity of the sward. It became evident during the first season's work that the facilities for the control of sheep ailments were inadequate, and the utilization of the grass during this season is ascribed mainly to the sheep having been seriously troubled with maggots and foot-rot. It will be noted that the utilization of the reseeded grass is shown to be particularly low when consumption is measured by either technique; and greater interference from foot-rot was occasioned on the reseeded plots than on the permanent pasture.

The data for 1946 in Table 3 show that according to Technique 1 the

grass consumed in the different groups of pastures provided very much the same amount of starch equivalent. On the other hand, Technique 2 shows a greater starch-equivalent production from the manured pastures than from the control pasture. The grazing animal, however, shows that the control pasture, the manured permanent pasture, and the manured reseeded pasture are in an ascending order of superiority. The reseeded pasture shows a definitely higher starch equivalent than the unmanured permanent pasture.

The grazing yield expressed as a percentage of grass-cutting indicates a very high efficiency of utilization of the grass, and this stands out in marked contrast to the low efficiency experienced in 1945. This is largely due to the more successful control of sheep ailments during this second season. Also whereas the welfare of the herbage received first priority during the season of sowing, the welfare of the grazing animal had the first consideration during 1946, and consequently the sheep and lambs were moved to fresh plots as soon as it was judged that the grazing was unsatisfactory.

The figures for the 1947 season show that the manured plots, both permanent and reseeded, were superior to the control pasture. There is, however, practically no difference between the grazing figures for the manured permanent-pasture plots and the manured reseeded plots. The results from Technique 1 show no appreciable difference between the three groups of pastures. The data from Technique 2 agree with those given by the grazing animal and differ from those obtained from Technique 1 by showing the manured plots, both permanent and reseeded, to be superior to the control pasture. The results from Technique 2 differ from the grazing data in showing that the manured permanent pasture gives a higher yield of starch equivalent than the manured reseeded pasture.

The means for the 3 years show the values in terms of starch equivalent to be greater in groups 2 and 3 than in group 1, the control pasture, both as regards the sheep-grazing and the grass-cutting techniques. This is especially so in Technique 2.

Discussion

The relative value of the treated pastures in relation to the control plots is obviously a matter of primary importance, and these relative values in terms of starch equivalent as given by the three methods of pasture evaluation are shown in Table 4. In this table the results for the second and third years only have been included, as adequate control of animal ailments had not been attained during the first year.

Technique 2 shows a greater difference than the grazing animal between the treated and control plots. Technique 1 shows a smaller difference. It is considered that the smaller response shown to treatment by the measurement under Technique 1 is partly due to the check to growth which the trimming adopted in this technique involved. During the experiment it was noticeable in dry periods that the trimming retarded growth especially on the reseeded plots, which were less densely covered than the permanent-pasture plots. The field on which

TABLE 4. *Estimated Starch Equivalents of Treated Pasture Plots in relation to Control Plots as measured by Grazing and Cutting (1946–7)*

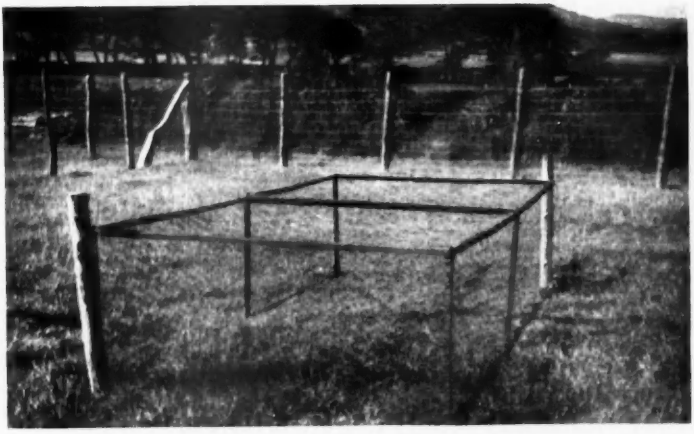
	Grazing			*Technique 1*			*Technique 2*		
	2nd year	*3rd year*	*Mean*	*2nd year*	*3rd year*	*Mean*	*2nd year*	*3rd year*	*Mean*
Group 1. Control plots .	100	100	100	100	100	100	100	100	100
Group 2. Manured permanent pasture . .	109	117	113	110	106	108	134	182	154
Group 3. Manured and reseeded . . .	121	120	121	106	95	101	131	136	134

the experiment was conducted is for the most part well-drained, and is exposed to the rapid drying action of easterly winds in spring. Consequently the conditions frequently occurred where the trimming under Technique 1 inflicted an undue checking effect on the growth of the reseeded areas. This probably accounts for the fact that whilst the mean relative starch equivalent (Table 4) from the manured permanent pasture is much the same whether it be measured by the grazing animal or by Technique 1, the relative starch equivalent for the reseeded plots (group 3) is less as measured under Technique 1 than when measured by the grazing animal.

At least a part of the starch equivalent provided by the grass must be used up in animal movement during grazing and not for maintenance or production, consequently it follows that a full 100 per cent. recovery of the starch equivalent provided by the grass cannot be expected from the animal measurements. When, however, the starch equivalent provided by the grass is measured according to Technique 1, it is found that more than a 100 per cent. recovery is forthcoming in animal maintenance and production. Thus the mean percentage recovery over the two harvest years is 103 for the permanent pasture and 123 for the reseeded grass. This points to the conclusion that the amount of starch equivalent as measured under Technique 1 is an underestimate of that actually consumed by the sheep, and that this technique gave a lower estimate of consumption for the reseeded grass than for the permanent pasture.

When we consider the results obtained from Technique 2, it is evident that the experimental errors involved are greater than with Technique 1. As indicated by Boyd [8] more cages are required for Technique 2 than for Technique 1 in order to attain the same accuracy, and care is needed to keep the plots closely and evenly grazed so as to obtain tolerably reliable results. It may be reasonably inferred, however, that Technique 2 gives an indication of the relative yields under conditions different from those under Technique 1 or under sheep-grazing. Technique 1 as used in this experiment gives information on the yield of grass available under conditions of severe treatment, where the grass is cut down to the ground and then allowed to grow for 3 weeks. The live-weight data, on the other hand, throw light on the yield of grass

a. A general view of the quarter-acre plots showing the type of country in which the trial was situated



b. The type of cage used consisted of one-inch angle iron and wire-netting, giving 4 ft. × 4 ft. ground area. Two cages are seen adjacent in the picture

c. Welsh mountain wethers used for determining live-weight increase in 1947. The method of fencing between the plots is also shown

available under very selective and controlled sheep-grazing, conditions in which the pasture was allowed a greater opportunity to recover than under Technique 1. In contrast both to the treatment under Technique 1 and under the sheep-grazing, the data from Technique 2 give information as to the relative yields under a more lenient and non-selective treatment.

Summary

Different methods of measuring pasture productivity have been studied on permanent and reseeded pasture plots over three growing seasons. One method consisted in measuring the rate of growth over a period of 3 weeks of the caged grass after trimming. The second method measured the difference between the yield from caged but untrimmed areas and the yield from adjacent grazed areas when the cage was set down 21 days previously. The cages in both methods were moved to a new randomly chosen site at intervals of 3 weeks. The third method of productivity measurement involved the weighing of sheep and lambs at the beginning and end of the experimental periods.

REFERENCES

1. P. A. Linehan and J. Lowe, The Output of Pasture and its Management. J. Brit. Grassland Soc., 1946, **1**, 7–35.
2. H. L. Ahlgren, A Comparison of Methods used in Evaluating the Results of Pasture Research. J. Amer. Soc. Agron., 1947, **39**, 240–59.
3. W. E. J. Milton and R. O. Davies, The Yield, Botanical and Chemical Composition of Natural Hill Herbage under Manuring, Controlled Grazing and Hay Conditions. J. Ecology, 1947, **35**, 65–95.
4. Ll. I. Jones, Variations in the Weight of Sheep. A Note as to Procedure. Welsh Plant Breeding Station, 1932, Bull. No. 13, Series H, 93–4.
5. E. J. Roberts and H. M. Williams, Grazing Trials on Old and Young Pasture at the College Farm, Aber, 1930–39. Welsh J. Agric., 1940, **16**, 111–31.
6. H. E. Woodman, Rations for Livestock. Min. Agric., 1948, Bull. No. 48.
7. S. J. Watson and E. A. Horton. Composition, Digestibility and Nutritive Value of Samples of Grassland Products. J. Agric. Sci., 1936, **26**, 142–54.
8. D. A. Boyd, Experiments with Leys and Permanent Grass. J. Brit. Grassland Soc., 1949, **4**, 1–10.

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BREEDING FOR DISEASE-RESISTANCE IN CANADA

PART III. HORTICULTURAL CROPS AND TOBACCO

A. W. S. HUNTER AND F. H. WHITE

(*Horticultural Division and Tobacco Division, respectively, Central Experimental Farm, Ottawa*)

BREEDING for resistance to disease in horticultural crops and tobacco has been conducted in Canada largely by the Dominion Department of Agriculture. An exception to this is the important work of the Ontario Department of Agriculture and the University of Toronto on leaf-mould resistance in tomatoes. Within the Dominion department two separate units are involved: the Division of Horticulture, the Tobacco Division, and the branch experimental stations of the Experimental Farms Service, and the Division of Botany and Plant Pathology and its branch laboratories of Science Service. The Divisions of Horticulture and Tobacco are concerned with the breeding, selection, and other aspects of the problem. The Division of Botany and Plant Pathology undertakes the required phytopathological studies and is responsible for the production of the inoculum, the inoculation of the plants, and the evaluation of their susceptibility. In the account that follows specific credit is not always given to the separate divisions, but it is to be understood that the work has been a co-operative effort.

Potato

The potato-breeding programme of the Dominion Department of Agriculture, centred at the Dominion Experimental Station and the Laboratory of Plant Pathology at Fredericton, N.B., has been reviewed by Young and Davies [1]; it was initiated in 1933 for the purpose of breeding for resistance to mild mosaic and late blight. In 1936 scab resistance was added, and since 1937 resistance to leaf-roll, a virus disease, has been included. Resistance to aphids has received some attention in recent years in co-operation with the Division of Entomology.

An indication of the extent of this work at Fredericton may be gained from the data in Table 1 showing the number of seedlings that have been produced in the various phases of the potato-disease-resistance project.

TABLE 1. *Number of Seedlings produced at Fredericton in Breeding Potatoes for Resistance to Disease and Aphids, 1934–48 inclusive*

Resistance to mild mosaic	33,640
Resistance to late blight	91,161
Resistance to common scab	25,393
Combined resistance to late blight and common scab	4,192
Resistance to leaf-roll	1,306
Resistance to aphids	3,349
Miscellaneous	2,852
Total	161,893

Late blight.—Late blight (*Phytophthora infestans* (Mont.) DeBy.) is a

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most destructive disease of potatoes in all parts of Canada, except the Prairie Provinces, and its control requires a costly protection programme. Resistance to late blight has been obtained principally from the wild species *Solanum demissum* Lindl. Definite progress has been made and some very highly resistant seedlings are now undergoing extensive trial. Two of these appear to be entirely satisfactory for use in some of the principal potato-growing sections and will be named and released for multiplication in 1950.

Common scab (*Streptomyces scabies* (Thaxt.) Waksman and Henrici).—This disease is of major importance in many of the better potato-growing regions of Canada, particularly in Quebec, Ontario, and the Prairie Provinces. The susceptibility of existing varieties prevents the use of lime to ensure an alkaline soil reaction, a condition necessary for the optimum production of such crops as clover and other legumes grown in the rotation by those engaged in mixed farming. Resistance to scab has been obtained from the European varieties Arnica, Hindenburg, and Richter's Jubel. It has not been difficult to produce seedlings that are highly resistant to scab, but almost invariably these seedlings have been late in maturity. However, several seedlings that are no later than Green Mountain and that have definite promise are under observation at the present time.

A limited attempt is also being made to combine resistance to late blight and scab in the same individual.

Leaf-roll.—This is the most serious virus disease affecting potatoes in Canada and there is no known source of a high degree of resistance to it. Much of the material in other phases of the programme has been subjected to tests for resistance to leaf-roll and a number of seedlings have been found that appear to possess considerable field-resistance.

Aphids.—Aphids are important because of their injury to the plants but more particularly because they are vectors of virus disease. That some varieties are highly resistant to the aphid *Myzus persicae* Sulzer has been shown by Adams [2], suggesting the possibility of controlling virus diseases by developing varieties that are resistant to aphids. This phase of the project is in its initial stages.

Potato-seedling and variety tests.—Promising selections, and also some unselected seedlings, produced at Fredericton are being tested across Canada through the National Potato Seedling and Variety Tests. These tests are conducted as a co-operative project, the Experimental Farms and Science Services of the Dominion Department of Agriculture, the various agricultural colleges, universities, provincial institutions, and private growers participating. It is hoped in this way to select disease-resistant varieties suited to the requirements of the different potato-growing regions. The existence of physiological races of late blight and scab makes such widespread testing very important.

Tomato

Leaf-mould.—Breeding for resistance to tomato leaf-mould (*Cladosporium fulvum* Cooke) has been conducted at the Horticultural Experiment Station of the Ontario Department of Agriculture, Vineland

Station, Ontario, in co-operation with the Departments of Botany and Zoology of the University of Toronto, Toronto, Ontario [3]. A study of the pathology of *C. fulvum* and of the genetics of resistance to it revealed the existence of several physiological races of the organism and of three independent dominant genetic factors for resistance or immunity [4]. An immunity factor, designated Cf_p1 and a resistance factor, Cf_p2, were found in the Red Currant tomato, a variety of *Lycopersicon pimpinellifolium* Mill. A second resistance factor Cf_{sc} was found in the *L. esculentum* variety Stirling Castle.

Four varieties of tomato resistant to leaf-mould have been introduced. Vetomold, released in 1939, carried the immunity factor Cf_p1 and was immune from all races of *C. fulvum* known at that time, but the appearance of a new race of the pathogen led to an early breakdown in immunity [5]. The variety V-121, introduced in 1941, contained the resistance factor Cf_p2 and was highly resistant, but not immune, to the new race of *C. fulvum* in addition to all the previously known races. The resistance of V-121 lasted only a few years because of the appearance of yet another race of *C. fulvum*. V-473, introduced in 1946, and Vulcan, introduced in 1950, contain Cf_p1 and Cf_{sc} and are susceptible to only two of the rarer forms of *C. fulvum*.

A number of lines incorporating immunity from all known races of *C. fulvum* will be released for preliminary commercial trial in 1950. These derive their immunity from *Lycopersicon hirsutum* Humb. and Bonpl. and *L. hirsutum* var. *glabratum* Muller [6].

Pea

Among the diseases of peas that have assumed considerable importance in Canada in recent years are those caused by *Ascochyta Pisi* Lib., *A. pinodes* L. K. Jones (*Mycosphaerella pinodes*), and *A. pinodella* L. K. Jones.

In 1939 a search was initiated by the Division of Horticulture at Ottawa for a source of resistance to *A. Pisi* and *A. pinodes*. More than 100 varieties, selections, and species were inoculated with one or both of these diseases. A high degree of resistance to *A. Pisi* was found in certain varieties, but no useful resistance to *A. pinodes* was discovered. Breeding is now under way in an attempt to combine resistance to *A. Pisi* with desirable horticultural qualities [7].

The existence of more than one physiological race of *A. Pisi* is indicated by the differential reaction of some varieties to certain isolates of the organism. The separation and identification of the different races is being studied by the Division of Botany and Plant Pathology at Ottawa.

Apple and Pear

Scab.—Many of the leading commercial varieties of apple grown in Canada are highly susceptible to apple scab (*Venturia inaequalis* (Cke.) Wint.), the control of which requires an expensive protection programme. Varieties differ in their reaction to scab. Hockey and Eidt [8] reported on the relative susceptibility of a number of varieties and on the foliar scab reaction of approximately 30,000 seedlings of known parentage

grown in a nursery without fungicidal protection. Complete immunity was not found in any of the seedlings from standard varieties and only a small number of resistant seedlings was discovered, the highest proportion being from crosses in which Red Winter Reinette and Yellow Transparent were parents. Bishop and Hockey [9] re-examined some of these trees at a later stage in their development. They found that the majority of the Yellow Transparent seedlings were highly resistant to scab on both the fruits and leaves, but that the progeny of Red Winter Reinette were very susceptible to scab on the fruit in the latter part of the season.

The nearest approach to immunity was observed in seedlings of *Malus pumila* var. *Niedzwetzkyana* (Dieck) Schneid. The variety Geneva, an Ottawa selection from this species [10], was the most resistant apple of any size that was found. It is not a commercial apple but it is being used as a parent.

Breeding for resistance to scab is being continued at the Dominion Experimental Station, Kentville, N.S., and at the Central Experimental Farm, Ottawa, Ontario.

Crown rot.—Crown rot of apple-trees (*Phytophthora cactorum* (Lib. and Cohn) Schroet.) is the cause of serious losses to orchard owners in all parts of Canada. Research on the susceptibility of varieties and the breeding of resistant root-stocks is centred at the Dominion Experimental Station and the Dominion Laboratory of Plant Pathology at Summerland, in the Okanagan Valley, British Columbia.

The results of artificial inoculation with crown rot of a number of varieties and seedlings of varieties have been reported by Welsh [11] and Fitzpatrick, Mellor, and Welsh [12]. Under the conditions of the experiment a high degree of scion- and root-resistance was shown by several varieties, particularly Antonovka and Columbia and their seedlings, and Dolgo, Haas, East Malling II, Robin, and Transcendent. Crosses have been made with some of the resistant material and work is being continued on their vegetative propagation and suitability as understocks.

Fire-blight.—Fire-blight (*Erwinia Amylovora* (Burr.) Winslow *et al.*) is a serious bacterial disease of some varieties of apple and pea, especially in those regions of Canada remote from large bodies of water. Varieties differ in their susceptibility to fire-blight; some are highly resistant and others, given the correct environmental conditions, are very susceptible. Crosses have been made at the Division of Horticulture, Ottawa, between resistant and susceptible varieties in a group of hardy pears originated at Ottawa from crosses between the hardy European sorts Kurskaya and Zuckerbirn and the varieties Clapp Favorite, Duchesse d'Angoulême, Flemish Beauty, and Winter Nelis.

The rapidly growing young plants were inoculated artificially several times with the fire-blight organism. Varieties differed in the proportion of resistant offspring produced, but of the 1,412 plants inoculated, 658 or 46·6 per cent. remained healthy. No information has yet been obtained on any other characteristics of these seedlings, but the selection of fire-blight resistant progeny by this method would appear to be quite feasible.

Strawberry

The strawberry in Canada is attacked by foliage diseases. The most generally destructive are powdery mildew (*Sphaerotheca Humuli* (D.C.) Burr), leaf-spot (*Mycosphaerella Fragariae* (Schw.) Lind.), leaf-scorch (*Diplocarpon Earliana* (Ell. and Ev.) Wolf), and leaf-blight (*Dendrophoma obscurans* (Ell. and Ev.) H. W. And.). Red stele (red core) caused by *Phytophthora Fragariae* Hickman causes considerable damage to the roots of strawberry plants in parts of Nova Scotia and British Columbia.

Breeding for resistance to red stele has recently been started at the Dominion Experimental Farm, Agassiz, B.C., and the Dominion Laboratory of Plant Pathology, Kentville, N.S. Although no formal breeding work has been undertaken with the other fungous diseases mentioned above, an attempt has been made at Ottawa to avoid the selection for further testing of seedlings that are susceptible to powdery mildew and leaf-spot. Seedlings susceptible to powdery mildew almost invariably become infected in the field each year so that their identification is not difficult, but field infection with leaf-spot varies from year to year and it rarely becomes epidemic in a field of plants grown from seed.

In a study of strawberry foliage diseases, Fall [13] showed that artificial inoculation with leaf-spot might eliminate seedlings which would show resistance to that disease under field conditions, since even varieties that possess a high degree of field resistance may become severely infected under optimum artificial conditions. Artificial inoculation is being used at Ottawa to introduce leaf-spot into the seedling plantation, selection being based on the spread of the disease in the field to fresh leaves.

Raspberry

Some fungous diseases of the red raspberry are of economic importance in Canada, although until quite recently spraying for their control has not been a common practice. The most important diseases are anthracnose (*Elsinoe veneta* (Burkh.) Jenkins), spur blight (*Didymella applanata* (Niessl) Sacc.), late yellow rust (*Pucciniastrum americanum* (Farl.) Arth.), and the powdery mildew (*Sphaerotheca Humuli* (D.C.) Burr.).

Information on the susceptibility to these diseases of a number of varieties has been collected by the Divisions of Horticulture, and Botany and Plant Pathology, at the Central Experimental Farm, Ottawa [14]. The Lloyd George—Newman 23 hybrids, such as Madawaska, Marcy, Rideau, Taylor, and Trent, are susceptible to anthracnose and spur blight but highly resistant to late yellow rust and powdery mildew. Viking and many of its seedlings, including the variety Ottawa, are susceptible to late yellow rust and powdery mildew. Latham is susceptible to powdery mildew. The two latter groups are relatively resistant to anthracnose and spur blight.

Anthracnose is one of the most injurious of these diseases. Since its spores are not wind-borne the disease spreads slowly from plant to plant and rarely becomes epidemic in a plantation of seedlings. In order to study the possibility of selecting for resistance to anthracnose in small

plants before setting out in the field, the Division of Botany and Plant Pathology at Ottawa has perfected a method of culturing the organism *in vitro*. Preliminary inoculations on a group of seedlings resulting from recent crosses by the Division of Horticulture were made in the summer of 1949. Infection of some of these seedlings was secured.

Currant

The production by the Division of Horticulture of black-currant varieties that are resistant to white-pine blister rust (*Cronartium ribicola* J. C. Fischer) has been reported by Hunter and Davis [15]. Two selections, now named Crusader and Coronet, have been widely grown in Canada and to a limited extent in the northern part of the United States and in England. They have been subjected to natural infection and appear to be everywhere completely resistant. On the basis of artificial inoculations with spores from different localities, Hahn [16] reports them to be 'immune from blister rust in the nice sense of that term'. Resistance to rust is dominant to susceptibility and is due to a single genetic factor [14].

Breeding for resistance to rust in red currants is also in progress at Ottawa. The source of resistance is the variety Viking. Only a few seedlings from a cross with Stephens No. 9 have been grown to maturity, but the report by Hahn [17] that Viking is immune from rust under field conditions and that this immunity is dominant to susceptibility, has been borne out by observations at Ottawa.

Tobacco

There are five main types of tobacco grown in Canada, namely, flue-cured, burley, dark, cigar, and pipe. Within each type are many distinctive varieties. The improvement of these, through breeding for disease-resistance, has been confined to three major diseases, namely, black root-rot, brown root-rot, and mosaic. These diseases occur generally throughout all the tobacco-growing districts but are most destructive in the Old Belt of south-western Ontario. It is expected that the New Belt, farther east, will become similarly affected as cropping of tobacco is continued throughout the years.

The back-cross method is generally used in tobacco breeding. Within each tobacco type, varieties that carry the resistance factors for the particular disease under investigation are selected. Each one is crossed with susceptible varieties having otherwise highly desirable characteristics. Resistant hybrid plants are selected from the F_1 or F_2 progenies, depending upon the type of inheritance of the disease factors, and back-crossed to the susceptible variety. Usually four to six back-crosses are made before uniform progenies are obtained which exhibit the desirable characteristics of the susceptible parent as well as resistance to the disease.

Black root-rot.—This disease is caused by the fungus *Thielaviopsis basicola* (Berk. & Br.) Ferraris, which is widespread and causes the most damage within the first month after transplanting to the field. It is particularly destructive on a neutral or alkaline soil. Usually a soil pH of 5·6 and lower will inhibit the activity of the organism. Symptoms of the

disease are reduced growth, black lesions on the roots, and greatly reduced root-system. Moderately infected plants may recover to some extent with dry warm weather.

The breeding for varieties resistant to black root-rot has been confined primarily to the Dominion Experimental Station, Harrow, Ontario, and the Tobacco Division, Central Experimental Farm, Ottawa, Ontario. The burley variety Harrow Velvet was developed at Harrow from a single-plant selection from material introduced from Kentucky, U.S.A., in 1929. This variety has been distributed to all the major burley-producing countries throughout the world and used successfully as a source of resistance in black root-rot breeding work. Harrow Velvet is a heavy yielder and produces a leaf of good quality, but has a tendency to develop with the leaves fairly upright and close to the stock, resulting in some difficulty in suckering. Two new burley varieties have been released by the Harrow Experimental Station [18]. The variety Haronova exhibits considerable resistance to both black and brown root-rot, whilst Harmony is resistant only to black root-rot. Both varieties have an advantage over Harrow Velvet in ease of suckering.

Resistance to black root-rot appears to be conditioned by two pairs of dominant factors so that the first hybrid generation, derived from a cross between resistant and susceptible varieties, is resistant. The F_2 or second generation segregates in the ratio of 15 resistant plants to 1 susceptible plant. Thus, resistance is fairly readily transferred to any given variety.

In the flue-cured type of tobacco, the variety Delcrest, released extensively to commercial growers in 1948, was developed at Harrow, Ontario, from a cross between a dark type resistant to black root-rot and White Mammoth, a flue-cured variety. In successive years, selected plants were crossed with the flue-cured variety Duquesne for earliness and the variety Gold Dollar for quality. Further selections were made for black root-rot resistance. In 1949, Delcrest made up about 35 per cent. of the Canadian flue-cured tobacco crop.

At the present time, fifty black root-rot resistant burley and dark strains in the fourth to sixth back-cross are being processed in preparation for testing in yield and quality trials at the Central Experimental Farm, Ottawa. Nineteen resistant cigar strains are now in the third year of testing for yield and quality, and the most favourable ones will be released to growers for large-scale tests in the near future.

Brown root-rot.—This disease has been a serious problem to tobacco growers for many years. No causal organism has been isolated, but the meadow nematode has been found to be closely associated with the disease in some areas. It is particularly destructive following a corn or soya bean crop. Susceptible varieties of tobacco are seriously reduced in growth in such cases. As a result of this observation, brown root-rot breeding-plots are grown on corn stubble, so that tobacco plants resistant to this disease may be selected from segregating populations.

Early observations indicated that varieties resistant to black root-rot were almost invariably susceptible to brown root-rot. It was thought that possibly the same factors, or others very closely linked on the same

chromosomes, were involved. Breeding work at the Harrow Station indicates that this linkage has been broken, since Haronova, a burley variety, is quite resistant to both black and brown root-rot. Several other burley and dark selections are also showing resistance to both diseases.

The genetic relationships of this disease are rather obscure owing to the difficulty of obtaining a 100 per cent. infection of susceptible plants. Infection usually appears in patches in the field. However, at the present time there are indications that resistance is dependent upon a pair or pairs of dominant factors, since the F_1 generation is partially resistant where a resistant and susceptible variety is hybridized.

Mosaic disease.—Tobacco mosaic, which is caused by a virus, is a common disease in the commercial tobacco fields of Canada. It is apt to become very serious where tobacco is grown on the same land in successive years, and where adequate precautions are not taken to avoid infecting the plants when handling the seedlings. Where early infection occurs, considerable reduction of yield and quality results. Late infection may damage relatively few leaves to the extent that they do not cure properly.

Resistance to tobacco mosaic is due to two pairs of recessive factors. This gives a segregation of 15 susceptible plants to 1 resistant plant in an F_2 progeny from a resistant $\times$ susceptible variety. In the breeding programme artificial inoculations are made on the segregating progenies at 6 weeks after planting in the field and at 2-week intervals thereafter. This is carried out by rubbing the leaf-extract of an infected plant on two leaves of each healthy plant. After a 2-week incubation period, mosaic resistant plants are selected for further back-crossing to the parent variety to be improved. The selected plants are also self-pollinated and inoculated the succeeding year to re-check their resistance.

At the present time, 48 strains in the fourth and sixth back-cross and the third to seventh generation are being tested in the mosaic breeding-programme as reported by MacRae [19]. Resistance to tobacco mosaic is obtained from a South American dark-type tobacco known as Ambalema. This variety was hybridized with the commercial flue-cured, burley, dark, and cigar varieties during 1937, so that resistant strains are now in an advanced stage of processing. These strains will be compared in replicated randomized trials with standard varieties when the desired characteristics have been fixed for each type.

In later work it is proposed to combine resistance to black root-rot with mosaic resistance for each of the commercial varieties into a single strain, rather than separate strains as they are now available.

Miscellaneous Horticultural Crops

Selection for resistance to downy mildew (*Peronospora Schachtii* Fuckel) within a particular strain of Detroit Dark Red garden beet is being conducted at the Dominion Laboratories of Plant Pathology and the Dominion Experimental Stations at Summerland and Saanichton in British Columbia.

A search is in progress at Ottawa for a source of resistance to the

bacterial diseases common blight (*Xanthomonas phaseoli* (E. F. Sm.) Dowson) and halo blight (*Pseudomonas phaseolicola* (Burk.) Dowson) of beans (*Phaseolus vulgaris* L.).

Selection and breeding for resistance to the tomato leaf-spots caused by *Septoria Lycopersici* Speg. and *Alternaria Solani* (E. and M.) Jones and Grout, are being conducted at the Dominion Experimental Station, Morden, Manitoba. The wild species *Lycopersicon peruvianum* (L.) Mill. is being used as the source of resistance. Late blight of tomato (*Phytophthora infestans* (Mont.) DeBy.) is causing mounting losses in eastern Canada. A search for a source of resistance that might be used in breeding is under way at Ottawa, and at the Ontario Agricultural College, Guelph, Ontario.

Dutch elm disease (*Ceratostomella Ulmi* (Schwartz) Buis.) has recently entered Quebec and Ontario, a region in which the susceptible American elm (*Ulmus americana* L.) is native and is also widely planted and highly prized as a shade tree. A project for the breeding or selection of suitable resistant types has been undertaken by the Dominion Experimental Station, L'Assomption, Quebec, and the Division of Horticulture, Ottawa.

REFERENCES

1. L. C. YOUNG and H. T. DAVIES, Dominion Expt. Stat., Fredericton, N.B. Progress Rept. 1937–47. Canada Dept. Agric., 1949, 74–9.
2. J. B. ADAMS, Amer. Potato J., 1946, **23**, 1–22.
3. D. L. BAILEY, Ontario Hort. Expt. Station, Vineland Reports 1945–6; 1947, 56–60.
4. A. N. LANGFORD, Can. J. Res. Sec. C, 1937, **15**, 108–28.
5. D. L. BAILEY and A. N. LANGFORD, 20th Ann. Rept. Canadian Plant Disease Survey, 1941, 57.
6. E. A. KERR, Personal communication, February 27, 1950.
7. L. H. LYALL, Reaction of Strains of Peas to Certain Blight Fungi, M.S. Thesis, University of Minnesota, St. Paul, Minn., 1947.
8. J. F. HOCKEY and C. C. EIDT, Sci. Agric., 1944, **24**, 542–50.
9. C. J. BISHOP and J. F. HOCKEY, Personal communication, December 3, 1948.
10. I. PRESTON, J. New York Bot. Gard., 1944, **45**, 169–74.
11. M. F. WELSH, Can. J. Res. Sec. C, 1942, **20**, 457–90.
12. R. E. FITZPATRICK, F. C. MELLOR, and M. F. WELSH, Sci. Agric., 1944, **24**, 533–41.
13. J. E. FALL, Foliage Diseases of the Strawberry, M.A. Thesis, University of Toronto, Toronto, Ontario, 1949.
14. A. W. S. HUNTER, Horticulture Division Prog. Rept. 1934–48. Canada Dept. Agric., 1950, in the press.
15. —— and M. B. DAVIS, Proc. Amer. Soc. Hort. Sci., 1943, **42**, 467–68.
16. G. G. HAHN, Phytopath., 1948, **38**, 453–56.
17. —— ibid., 1936, **26**, 860–75.
18. R. J. HASLAM, 'The Lighter', Tobacco Division, Canada Dept. of Agric., Feb., 1949, **19**, 1.
19. N. A. MACRAE, Tobacco Division Prog. Rept. 1935–48, Canada Dept. Agric., 1950, 17–18.

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AGRONOMIC AND BREEDING RESEARCH ON RICE, OIL-PALMS, AND CACAO IN MALAYA

PART I. RICE

R. G. H. WILSHAW

(*Chief Research Officer, Department of Agriculture, Federation of Malaya*)

Introduction.—MALAYA, which is roughly the size of England and Wales, covers an area of 51,200 sq. miles; 80 per cent. of the country is still under forest.

Included in this 80 per cent. are large areas of forest reserves, swamp forest, and forest areas too mountainous or steep for agriculture. After allowing for all known reserves, land over 750 ft., and land already under crops, it is estimated that there remains an area of about 17,000 sq. miles on the plains of Malaya which is available for development. It is known, however, that this figure includes considerable areas of deep swamp land, raised sandy beaches, and other types of land unsuited for agriculture, and until further surveys have been undertaken it would be unwise to assume that there is more than 8,000–10,000 sq. miles (5–6½ million acres) of lowland which could be used for agricultural purposes.

Of the 20 per cent. of the country which is already opened up, four-fifths, or 16 per cent. of the whole, is under agricultural crops covering about 5·2 m. acres. In 1947 the approximate division of this acreage between the main crops grown and between estates and smallholders is shown in the following table:

TABLE 1. *Acreages of Land under Main Crops owned by Estates and Smallholders*

Crop	*Estates*	*Smallholders*	*Total*
Rubber	1,945,621	1,398,631	3,344,252
Coconuts	86,386	433,600	519,986
Padi	Nil	813,538	813,538
Oil-palm	78,181	Nil	78,181
Pineapples	Nil	12,070	12,070
Tea	9,732	Nil	9,732
Coffee	Nil	8,958	8,958
Food crops (less padi)	Nil	112,090	112,090
Fruits (less pines)	Nil	174,450	174,450
Spices	Nil	59,986	59,986
Miscellaneous	4,449	43,015	47,464
Total	2,124,369	3,056,338	5,180,707

Although rubber occupies a preponderant position in covering 64 per cent. of the area under crops, it will be seen that substantial acreages are at present under padi, coconuts, food crops other than padi, fruit, oil-palm, and spices. Other crops which either have now, or may have in the future, economic importance are tea, pineapples, and possibly cacao.

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The object of this article is to review briefly the present position of investigations carried out by the Department of Agriculture on rice in Malaya, and to indicate the lines of future advance. A subsequent article will deal with oil-palms and cacao.

The late war naturally caused a serious break in the continuity of investigational work and the loss of many records, and as a result in many cases a fresh start has had to be made. More recently the existing disturbed conditions in Malaya have caused difficulty in maintaining organized experimental programmes.

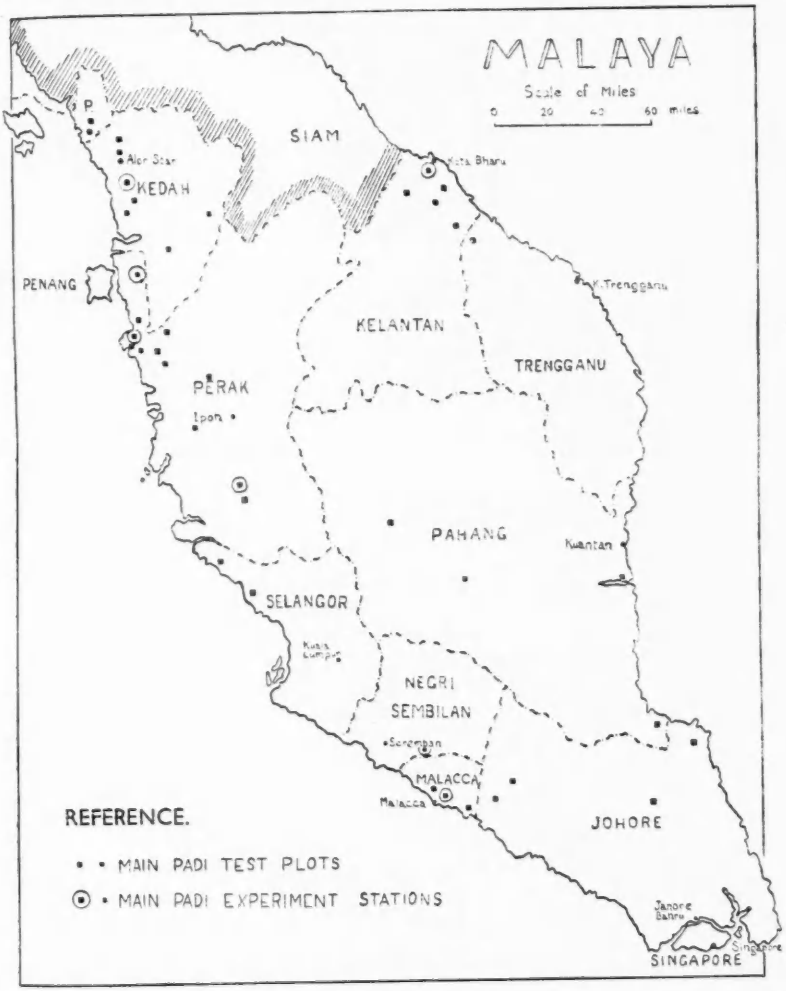
RICE is the staple food of the majority of the population in Malaya and is grown entirely on native holdings. The area under production in 1949 is estimated at slightly over 900,000 acres, 93 per cent. of which is under wet padi. The average yield of wet padi for 1949 is estimated at 0·45 ton per acre of rice, giving an approximate production of 400,000 t. If unrestricted imports were allowed, this production would probably account for between 35 and 40 per cent. of the country's consumption.

For many years past, intensive efforts have been made to increase the total production both by extending the area under cultivation and by increasing the yield per acre. The progress made in this direction can be estimated by comparison of the 1949 figures given above with those of the period 1924–30 when production was estimated at 200,000 t. per year from 650,000 acres. Although production has been doubled in the last 20 years, the increase has been offset by the natural increase in population. Whilst the considerable increase in acreage is due to a great extent to the development work carried out by the Drainage and Irrigation Department, some at least of the increase in yield per acre may fairly be attributed to the research work carried out by the Department of Agriculture both on agronomic and botanical lines.

Agronomic investigations.—From 1930 to 1940 an extensive series of manurial and cultivation trials was carried out in all main padi-growing districts of Malaya, and results have been fully reported [1]. At the end of this period the indications were that the heavy padi soils of the western side of the Peninsula were only slightly responsive to manuring, such response as existed being an uneconomic one to phosphate, whilst no improved cultivation methods had been evolved. On the other hand, the lighter padi soils of the eastern side of the Peninsula gave indications of responding both to manurial treatments and improved methods of cultivation.

After the war, owing to the acute shortage of rice in south-east Asia, the main activities of the Department were devoted to increasing as rapidly as possible the total acreage under padi, and it was not until the 1948–9 season that field experimental work could again be undertaken. During the last season, however, seventy field experiments were in progress at Departmental Stations investigating the following factors: time and depths of ploughing; seed-rates; methods of sowing; single and double cropping; methods of weed control both agronomic and chemical; influence of off-season cultivation on subsequent rice crops; fertilizer treatments; and fertilizer placement. One series of experiments testing

certain local methods of cultivation, at present in the second year of a 5-year course, has already shown indications on one, rather limited, soil type that puddling the soil by means of buffaloes gives higher yields than



ploughing and harrowing or hoeing or slashing. Sowing trials carried out in connexion with mechanical cultivation have indicated that a satisfactory stand of padi may be obtained by broadcasting seed, and that best results are likely to be obtained if the seed is soaked and germinated before sowing and then dropped into clear shallow water 2 in. deep. The practical application of this result has yet to be investigated. The

first season of post-war manurial trials just concluded has shown that a high increase in yield of padi in Kelantan may be obtained by the placement of mono-ammonium phosphate in small packets immediately below the growing plant. Pot experiments on the influence of trace elements have not so far indicated any specific element as being a limiting factor to the growth of padi.

Extensive investigations have also been carried out since the war into the possibilities of increasing the acreage under production by the use of mechanical equipment, and increasing the rate of production by improved methods of cultivation by the same means. Full accounts of the progress so far made, and the difficulties encountered, have been published in various numbers of the *Malayan Agricultural Journal* [2]. There are two distinct sets of problems involved depending on whether cultivation is being carried out on clay or peat soils.

Nearly all existing padi land in Malaya is of the clay type, and in most cases it has been broken up into small individual holdings. The problem on these smallholdings is to find out if mechanization can increase yields through more efficient methods of cultivation and weed control or, alternatively, if, by its use in speeding up cultivation operations, double-cropping can be carried out. The size of the individual holdings seems to preclude the practice of mechanized drilling or harvesting. Problems associated with these two aspects of mechanization would, however, arise should future surveys of existing swamp jungle reveal extensive areas of clay soils. At present this does not appear a likely probability, all the indications being that most of the existing swamp areas are covered with a layer of peat. The work carried out so far on clay soils has shown that with the exception of very deep clays near the coast wheeled tractors with standard equipment will be reasonably satisfactory.

Peat soils on the other hand present an entirely different set of problems. There are considerable areas of these soils in Malaya topographically suitable for wet padi, mostly under forest at present. If they could be brought under large-scale fully mechanized cultivation and made to grow satisfactory crops of padi, they would help considerably in narrowing the gap between the country's consumption and production of rice. The problems here involved, however, are great. In the first place, there arises the difficulty of clearing forest from wet peatland, which offers no purchase for felling or hauling machinery. Then comes the question of draining the area to a sufficient degree of dryness to enable the soil to carry the weight of a crawler type of tractor. After this comes the problem of buried timber that abounds in these peat soils, and which, unless removed, will clearly render the use of cultivation implements impracticable.

All these problems together with the future programme of experimental work on mechanized rice cultivation are at present under review following a recent visit to Malaya by Dr. E. W. Russell and Mr. J. C. Hawkins at the instance of the Colonial Advisory Council of Agriculture.

Selection and breeding work.—The selection and breeding work that has been carried out over a number of years in Malaya has shown that

padi is very sensitive to changes in environment. It is now recognized that there exist in Malaya about fifteen distinct ecological areas for each of which it is eventually likely that separate breeding work will have to be carried out. In the first instance, however, efforts have been concentrated on breeding for four or five of the main padi-growing districts. In padi-breeding work in Malaya, in addition to such characters as yield and strength of straw, attention must always be paid to such factors as palatability, which is assessed differently in different areas, and machine and hand-milling qualities.

Reviews of the breeding, selection, and varietal trial work carried out up to 1940 have been published from time to time [3]. A summary of the position reached at the outbreak of war is as follows:

In the extensive padi-growing area of North Kedah and Perlis (250,000 acres) two varieties, Mayang Ebos and Radin China, were the predominant and popular milling types, grown, it is estimated, by three-quarters of the padi planters. By 1940 four pure-line selections of these varieties, Mayang Ebos 80 and 88 and Radin China 4 and 7, had proved acceptable and popular, and at least half of the planters accustomed to plant these varieties were using seed of Mayang Ebos 80. The Mayang Ebos strains were capable under good conditions of yielding almost 1 t. of rice per acre.

In the Krian District of North Malaya two strains for growing in deep water and of long-maturation period, Seraup 36 and 48, had been extensively adopted. They were capable, under good conditions, of yielding 1·25 t. of rice per acre and were grown for sale to the mills, but their cooking and eating qualities were not of the highest standards.

In Malacca selection work had been carried out on three distinct types of padi. On the Nachin type two selections, Nachin 10 and 11, had been adopted as particularly suitable to the rather poor soils of this area; under good conditions they were capable of yielding 0·7 t. of rice per acre.

Two lines of a short-term variety of padi had been selected, Radin Siak 17 and 34, which proved valuable under conditions requiring their use.

A further selected line was Siam 29, a high-yielding, high-quality rice suffering, however, from a weak straw. It was grown throughout Malaya, but to a large extent by those who were prepared to take the risk of lodging in exchange for its yield and quality.

During the Japanese occupation most of the pure-line selections, except those maintained at Telok Chengai Padi Experiment Station in the State of Kedah, were either lost or became badly contaminated. In Kedah, however, the two Mayang Ebos selections, the two Radin China selections and Siam 29 which had been taken up to that district, remained apparently pure. Other selected strains were still being grown in greater or less degree but could not be regarded as having been maintained as pure lines.

In 1947 selection work started afresh and is now in progress. The general programme is to reselect amongst the most widely grown and generally popular varieties but over a wider field than had been done in the past.

In Kedah reselection of a combined Radin-Ebos foundation stock of Mayang Ebos and Radin China is in progress. In Krian reselection of Seraup types with particular attention to cooking and eating qualities is being undertaken. Reselection of Siam and Nachin types is also in progress in Malacca with especial emphasis on strength of straw. Work has also been commenced on selection of varieties suitable for Negri Sembilan and Penang.

Elsewhere varietal surveys are in progress and at Padi Stations on the west coast 396 medium and 140 long-term varieties are under observation. Similarly in Kelantan 365 varieties have been collected and are being studied for selection of types suitable for the east coast of Malaya.

REFERENCES

1. W. N. C. Belgrave and R. G. H. Wilshaw, Malayan Agricultural Journal, 1931–9, Vols. **19–27.**
2. Various authors, ibid., 1948, **31,** 20–47.
3. B. A. Lowe, R. B. Jagoe, and F. Birkinshaw, ibid., 1931–41, Vols. **19–29.**

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